CHEMICAL ENGINEERING

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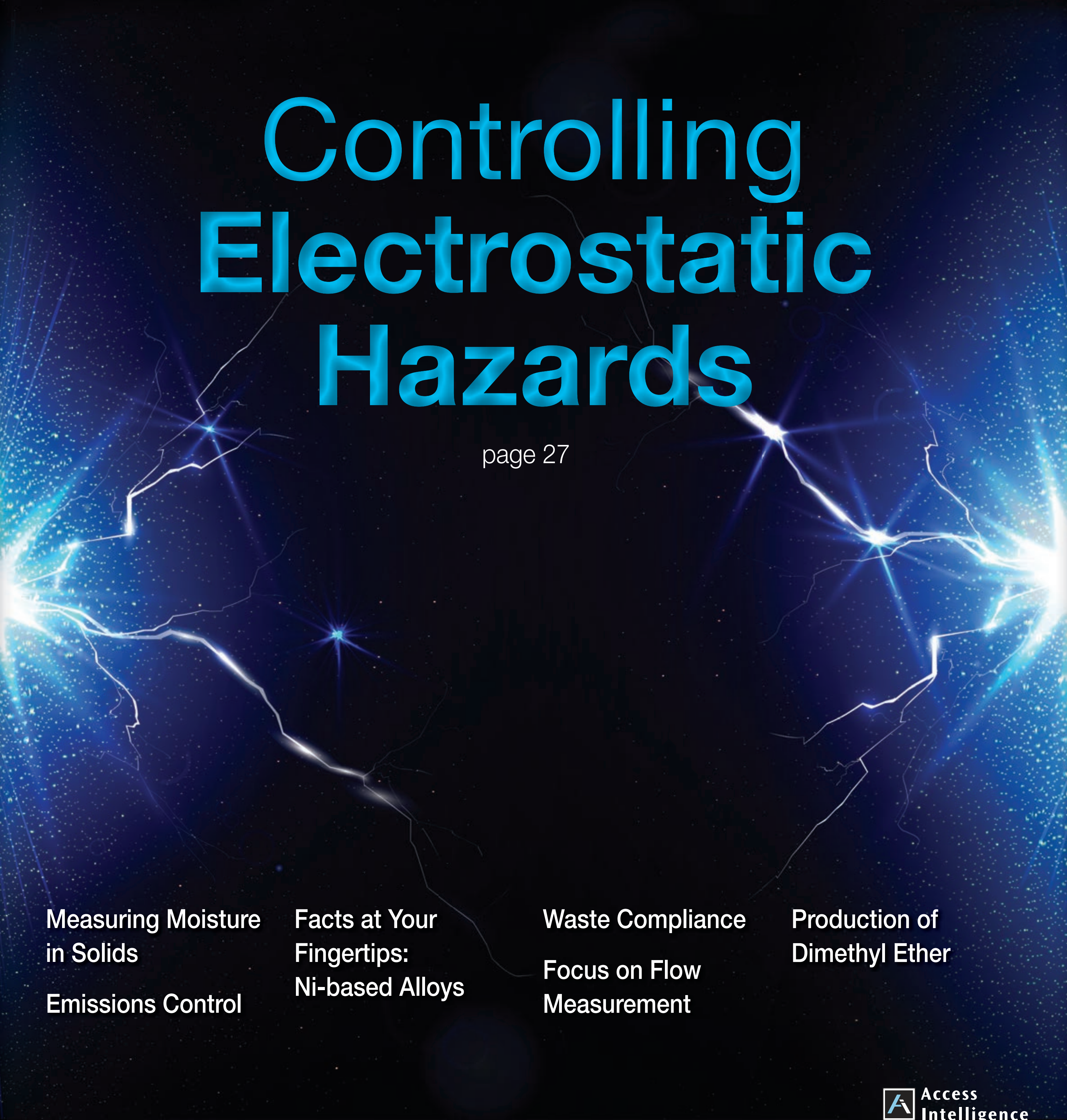
January 2021



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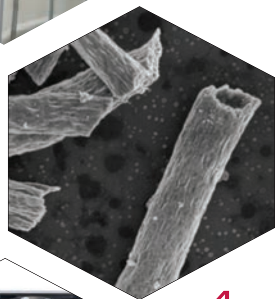
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Coming in February

Look for: **Feature Reports** on Energy Efficiency; and Protecting Steam Systems from Corrosion; A **Focus** on Packaging; A **Facts at your Fingertips** on Pressure Relief; a **Newsfront** on Heat Exchangers; **New Products**; and much more

Cover design: Tara Bekman

Editor's Page

The 2021 Kirkpatrick Award: Call for nominations

Since 1933, *Chemical Engineering* has honored noteworthy chemical engineering technologies that have advanced to the commercialization phase. These technologies generally seek to develop new processes or improve current ones, often with targets of better efficiency, new or improved products and greater sustainability. CE seeks to honor these achievements. Every two years, technologies that have been commercialized in the previous two years are nominated and evaluated, and the winning technology is awarded the Kirkpatrick Chemical Engineering Achievement Award. Nominations are now being accepted for the 2021 award.

In 2019, the 45th Kirkpatrick Chemical Engineering Achievement Award was presented to LanzaTech (Chicago, Ill.; www.lanzatech.com) for its gas fermentation technology, which converts carbon-rich gas streams to products using proprietary microbes that feed on gases rather than sugars, as in traditional fermentation. Details of the winning achievement and the honorable mentions can be found in our January 2020 issue (Gas Fermentation Leads Honored Achievements, pp. 23–26). This achievement joins the distinguished list of past winners, which includes CB&I and Albemarle Corp., for the AlkyClean process — the world's first solid-catalyst alkylation process (2017). The full list of past winners can be found at www.chemengonline.com/kirkpatrick.

How to nominate

Nominations may be submitted by any person or company, worldwide. The procedure consists simply of sending, by March 15, an unillustrated nominating brief of up to 500 words to: awards@chemengonline.com.

In order to be considered, each nomination should include the following: 1) a summary of the achievement and novelty of the technology; 2) a description of the difficult chemical-engineering problems solved; and 3) a description of how, where and when the development first became commercial in 2019 or 2020.

If you know of an achievement but do not have information to write a brief, you can contact the company involved, either to get the information or to propose that the firm itself submit a nomination. Companies are also welcome to nominate achievements of their own.

The selection process

After the deadline for nominations (March 15) we will review the nominations for validity. The nominations will then be sent to heads of accredited university chemical-engineering departments, who will vote, independently of each other, for a maximum of five best achievements.

The entries that collectively receive the most votes become the finalists in the competition. Each finalist company will then be asked to submit more-detailed information, such as a description of the technology, performance data and examples of the teamwork that generated the achievement.

Copies of these detailed packages will be sent to a Board of Judges.The Board will judge the entries to select the most noteworthy. The company that developed that achievement will be named the winner of the 2021 Kirkpatrick Chemical Engineering Achievement Award and the other finalist companies will be designated to receive Honor Awards. The awards will be bestowed in the fall. ■

Dorothy Lozowski, Editorial Director

Edited by:
Gerald Ondrey

Membrane-based system for low-cost CO_2 capture to be demonstrated at engineering scale

A new membrane technology for separating carbon dioxide from exhaust gas will be scaled up for real-world testing under a project to evaluate low-cost CO_2 capture at a coal-fired power plant. Design and testing of an engineering-scale CO_2-capture system will be jointly overseen by GTI (Des Plaines, Ill; www.gti.energy) and The Ohio State University (Columbus, Ohio; www.osu.edu). The project aims to conduct tests on coal fluegas at the Wyoming Integrated Test Center.

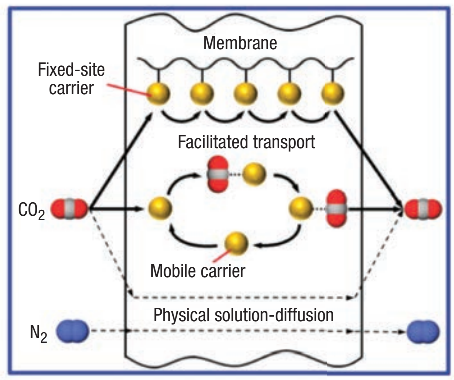
The CO_2-selective membrane, developed by Ohio State researchers, consists of a layer of non-volatile, amino-group-containing compounds coated onto a nanoporous polymer support. When CO_2-containing fluegas contacts the membrane, CO_2 molecules dissolve into the membrane by combining reversibly with the amino groups in the membrane to form protonated amine cations and bicarbonate anions. The ions are transported across the membrane via two separate routes in a "facilitated transport" mechanism — in the first, the CO_2 molecule "hops" from one covalently bound amino-group site to subsequent adjacent sites, and in the second, CO_2 reacts with a mobile carrier (an amino acid salt) that diffuses across the membrane (diagram). CO_2 is released to the low-pressure side of the membrane when it desorbs from the amino sites, leaving them in the membrane.

Since trans-membrane diffusion of other fluegas components (mostly N_2, which cannot react with the amino sites) is extremely slow, the membrane can selectively separate CO_2 from a fluegas stream.

Membrane-based CO_2 capture has advantages, Ohio State professor Winston Ho explains: "The membrane combines the absorption and desorption of CO_2 onto and off of the amino sites into a single step, so no amine regeneration is required as in conventional absorption-based technology. Therefore, we can avoid the 'energy penalty' that you would find for carbon capture based on amine solutions." Further, the membrane system can operate continuously, while solution-based CO_2 capture requires two stages: absorption and regeneration. "And by converting the amino groups to sterically hindered amines using bulky isopropyl groups, for example, we can increase the CO_2 sorption capacity," adds Ohio State research scientist Yang Han.

The Ohio State team has rolled the membrane material into 21-in. by 8-in.-dia. spiral-wound modules for inclusion in the test project, which has a goal of capturing CO_2 at 95% purity and a cost of \$30 per ton of CO_2 captured. Performing engineering-scale studies and maturing technology in a real-world environment will help validate the system for market introduction and move it into utility and industrial use at new and existing facilities, according to the project coordinator, GTI's Shiguang Li.

Ohio State University

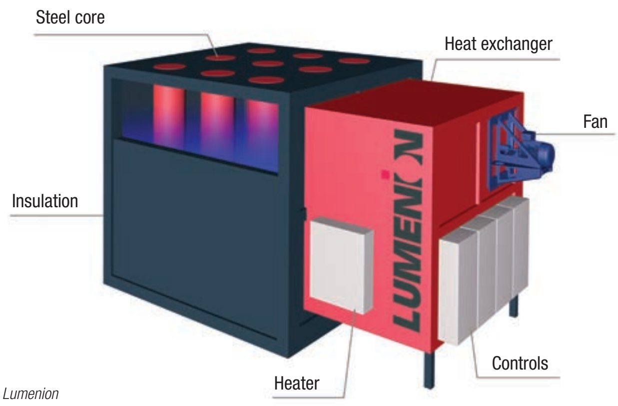


The project was selected for funding by the U.S. Department of Energy's National Energy Technology Laboratory (Morgantown, W.Va.; www.netl.doe.gov).

Storing excess electricity as high-temperature heat

Late last November, the energy-transition startup company Lumenion GmbH (Berlin, Germany; www.lumenion.com) received the 2020 Berlin Brandenburg Innovation Prize for its high-temperature, steel-based energy-storage technology. The system stores peaks of wind and solar energy by heating a steel core to temperaures of up to 650°C. Steel was selected because its thermal conductivity makes it easy and inexpensive to heat. Insulation keeps the steel hot until it is needed, either as process heat for industry, or for district heating (diagram). Because of the high storage temperature, it is also possible to convert some (about 25%) of the thermal energy back into electricity using a turbine. The system has a 95% efficiency (25% electric, 70% thermal) when used for combined power and heat distribution.

The technology was first tested with a 450-kWh prototype on the campus of Berlin's University of Applied Sciences. In December 2019, a 2.4-MWh storage system was integrated into the district electricity and local heating supply of a residential estate in Berlin-Tegel, operated by Vattenfall Energy Solutions GmbH. This system started up in August 2020 as part of the WindNODE program. Lumenion plans to develop further systems with 40 or even 500 MWh.



Lumenion

MDI PRODUCTION

Late last year, Covestro AG (Leverkusen, Germany; www.covestro.com) started up a pilot plant for the production of methylene diphenyl diisocyanate (MDI) based on the innovative AdiP (adiabatic-isothermal phosgenation) technology at its Brunsbüttel site. The new technology promises to significantly improve energy efficiency and marks an important milestone for Covestro in its orientation towards the circular economy.

The AdiP reaction is controlled more efficiently and does not require an external heat supply, because the heat generated during the reaction process is used. As a result, this production process significantly reduces energy consumption and CO_2 emissions in MDI production. Thanks to AdiP technology, up to 40% steam and 25% electricity can be saved per ton of MDI produced in an MDI plant — and CO_2 emissions are thus reduced by up to 35%, says the company. In addition, the production output increases by 50% compared to the technology currently in use. As a result, future MDI production plants based on AdiP technology can be smaller than in the past, says Covestro.

The pilot phase should be completed in about 12 months.

H_2O_2 GENERATOR

Late last November, Evonik Industries AG (Essen, Germany; www.evonik.com) made a second investment in HPNow (Copenhagen, Denmark; www.hpnow.eu) through its venture capital unit. Evonik participated in the first financing round of the start-up as early as 2017. The London-based venture capital specialist AP Ventures (London, U.K.) was the co-investor for this latest €5-million financing round.

HPNow has developed a modular generator, called HPGen, that produces hydrogen peroxide directly on site by a patented electrochemical technology. This technology makes it possible to use H_2O_2 even in places to which transport has been uneconomical or even impossible until now. The system only requires electricity, water and air.

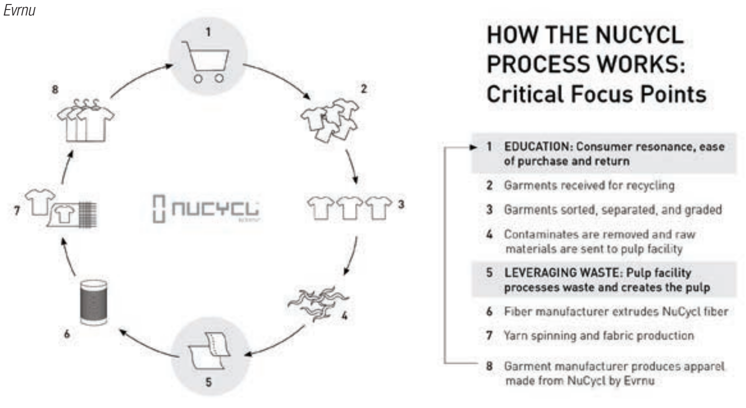
To date, HPNow mainly focused on water-treatment in agricultural applications, such as drip irrigation, and more recently in dishwashers. Following its successful entry into the agricultural market, HPNow is now

(Continues on p. 7)

Process allowing recycling of cotton garments produces multi-ton quantities for testing

A process developed by Evrnu (Seattle, Wash.; www.evrnu.com) to regenerate cotton fibers from waste fabric and post-consumer garments has been used to produce ton quantities of recycled cotton fiber for testing. An economically viable process for recycling cotton would have the environmental benefits of drastically reducing the amount of landfilled or incinerated fabric, which currently totals millions of tons annually, while also reducing the amount of land and water required to grow the cotton plants.

Evrnu



Evrnu has developed an end-to-end process, known as NuCycl, that includes sorting fabrics to identify the types of fibers in the textile, shredding the textiles and removing the dyes and additives (diagram). The cotton then enters a reactor, where it is depolymerized, using a range of solvent blends and ionic liquids, to create a pulp that is finally extruded into new fiber.

"We've used a targeted innovation approach to deconstruct cotton textiles at the molecular level to create a range of regenerated cellulose fibers with different molecular weights that are stronger and more durable than the original fabrics," says Christopher Stanev, co-founder of Evrnu. "The NuCycl process can be run with modest retrofitting at existing pulp mills," he adds, so "paper mills can convert existing lines to garment recycling, rather than shutting down as demand for paper declines."

Evrnu is partnering with large retailers and waste companies to collect waste textiles, unsold material and post-consumer garments, as well as with consumer brands, such as Stella McCartney, Target, Levi's and Adidas, to make clothing from recycled fibers. The company now offers commercial licenses on its technology to players in the textile industry.

In addition to cotton and natural-fiber recycling, the company is also developing other textile-recycling processes for materials such as synthetic fibers (polyester), polyester/cotton blends and Lycra.

A coating for windows that also cools

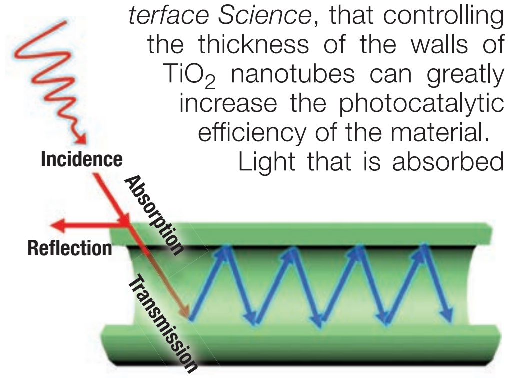
A Korean team has proposed an approach for passive radiative cooling. The team, which includes professors Junsuk Rho and Jin Kon Kim of Pohang Universiy of Science and Technology (Pohang, South Korea; www.postech.ac.kr) and professor Heon Lee of Korea University (Seoul, South Korea; www.korea.ac.kr), says its work demonstrates that a simple and low-cost single membrane can be used to produce efficient daytime radiative cooling, whereas many previous methods have required the precise design of multilayers and patterns. "We believe our approach is suitable for the mass production of a low-cost radiative cooler which would help reduce global energy consumption," the researchers say.

The researchers used porous anodic-aluminum-oxide (AAO) coated with thin layers of SiO_2. The AAO shows near perfect spectral emissivity in the atmospheric window in the mid-infrared spectrum (8–13 μm). According to the team, conventional AAO has a large extinction coefficient over 10 μm, and by itself does not produce the required near perfect spectral emissivity band over the entire atmospheric window.

The SiO_2-coated AAO membrane shows an average cooling flux of 65.6 W/m^2 during the daytime, and a maximum cooling of 6.1°C below ambient temperature under direct sunlight. The final design exhibited a high reflectance of 0.86 in the solar spectral region, and an average emissivity of 0.96 in the atmospheric window.

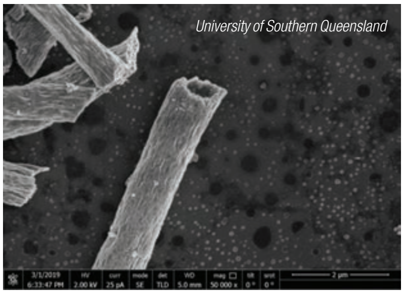
Enhancing photocatalytic activity by tuning wall thickness of TiO_2 nanotubes

Titanium dioxide is well known as a photocatalyst, and is especially promising for degrading organic-based contaminant molecules in wastewater. Researchers from China and Australia have reported, in a recent issue of the *Journal of Colloid and Interface Science*, that controlling the thickness of the walls of TiO_2 nanotubes can greatly increase the photocatalytic efficiency of the material. Light that is absorbed into the tubes is scattered along its internal surface (diagram), kicking electrons into high energy states, where they can then promote the chemical reactions being catalyzed. The research team has devised a method to control the thickness of the walls of the tubes, and has investigated the effect that varying thicknesses have on the efficiency of the light harvesting and catalytic behavior.



University of Southern Queensland

"Our strategy to adjust the wall thickness of TiO_2 nanotubes and microtubes opens a new approach to enhance the photocatalytic performance of TiO_2," says corresponding author Zhi-Gang Chen at the University of Southern Queensland (Australia; www.usq.edu.au). Other members of the team are based at Shaanxi University of Science and Technology (China).


University of Southern Queensland

The nanotubes (photo) are prepared using a one-step electrospinning method linked with a calcination process. The wall thickness of TiO_2 microtubes can be easily tuned by altering the dosage of liquid paraffin. The photocatalytic activity was compared for nanotubes with five different wall thicknesses. The most effective version of the tubes was able to catalyze the degradation of two sample wastewater contaminants — dinitrophenol and rhodamine — with 99.9% and 97.8% efficiency, respectively.

Chen points out that compared with other ways of making the catalytic tubes, their electrospinning method offers advantages of better control, lower costs and greater versatility in the materials to which it could be applied. Similar improvements in catalysts other than TiO_2 can be expected in the future.

Immobilizing enzymes for biosensors

A new technique for making less-expensive, more-efficient biological enzyme hybrids could have widespread applications, including in water recycling, drug manufacturing and molecular biology. The technique, developed by a team from Australia and the U.S., involves using a vortex fluidic device (VFD) to immobilize an enzyme hybrid, making it possible to reuse the enzyme under continuous flow.

The team, which includes professor Colin Raston from Flinders University (Adelaide, Australia; www.flinders.edu.au) and professor Gregory Weiss from the University of California at Irvine (www.uci.edu), reported details of a low-cost VFD that has a rapidly rotating tube open at one end. At high rotational speed, intense shear is generated at the open end in the resulting thin films. The device can also operate under a continuous-flow mode with jet feeds delivering liquid into the rotating tube, where additional shear is generated.

Harnessing the high shear forces and micro mixing in a VFD resulted in a dramatically accelerated fabrication of hybrid protein-$Cu_3(PO_4)_2$ "nanoflowers." The team was able to generate and immobilize the nanoflowers into silica hydrogel. This greatly simplified the fabrication process, and allowed reusing the enzyme. It also increased the enzyme's catalytic rates by 16 times. This technique overcomes some of the drawbacks of using enzymes in biosensors, such as cost and limited life of the enzymes — most enzymes become inactive during the assay process and cannot be reused.

The study was published in the November 5, 2020 issue of the ACS journal, *Applied Materials & Interfaces.*

also entering markets for the treatment of industrial wastewater with high oxygen demand, for advanced oxidation in municipal water treatment, and for use in cooling systems.

NEW GAS ENGINE

Late last November, field testing began on the world's first large-scale (1 MW) gas engine that can be operated with either 100% natural gas, or with variable hydrogen-natural-gas mixtures up to 100% H_2. The converted combined heat and power (CHP) plant in the Othmarschen area of Hamburg, Germany is part of the joint project of engine builder INNIO Jenbacher (Jenbach, Austria; www.innio.com), the energy service provider HanseWerk Natur GmbH.

The converted CHP plant provides 30 residential buildings, a sports center, a daycare center, and the Othmarschen Park leisure complex with a reliable supply of local heating that equates to 13,000 MWh every year. The electricity generated is fed to electric-vehicle charging points in Othmarschen's multi-level parking garage as well as to the local power grid.

"Our joint project with HanseWerk Natur is a key milestone on the path toward climate neutrality, since green hydrogen is an important part of the solution," says Carlos Lange, president and CEO of INNIO. "A particularly attractive aspect of our gas engine technology is that existing natural gas engines can also be converted to run on hydrogen. This offers operators security of investment, with the added benefit that the existing infrastructure can not only be utilized in the longer term, but also deployed in a way that is environmentally sound," says Lange.

DECONTAMINATE NUTS

Researchers at the Fraunhofer Institute for Environment, Safety and Energy Technology (UMSICHT; Oberhausen, Germany; www.umsicht.fraunhofer.de) have developed a new process that uses

(Continues on p. 8)

compressed carbon dioxide to decontaminate almonds, nuts and other dry foodstuffs. In a joint project with the University of Alberta (Canada) and supported by the German Federal Ministry of Education and Research (BMBF; Bonn), UMSICHT researcher Karen Fuchs and her team investigated technologies that could serve to decontaminate almonds.

"It is common knowledge that pressurized CO_2 can kill pathogenic bacteria in liquids, such as orange juice. Our research has shown that under certain conditions this also works with dry food," says Fuchs. In one process step, almonds are decontaminated and impregnated with antimicrobial oils using compressed CO_2 in a high-pressure autoclave. The oil extract coats the almond, making it difficult for germs to re-contaminate the fruit. The advantage of this process is that almonds retain their characteristic flavor and quality. Fuchs and her team carried out tests with *Staphylococcus carnosus*, a surrogate organism known for an even more resistant reaction than *Salmonella*, proving that the process in the autoclave does not adversely affect the shelf life, rancidity or lipid composition of almonds. This process also lends itself to other foods.

DRUM DECANTING

Last month, Cellier Blending and Formulation Solutions (Aix les Bains, France), part of ABB France (www.abb.com), introduced its High Viscosity Drum Decanting System, which is designed to pump and dose highly viscous liquids stored in drums and incorporate them into the formulation process. The automated system is designed to increase pumping capacity of highly viscous products by up to 20,000 centistokes and to reduce operator drum handling time by 50%. Immediately after pumping is completed, materials are automatically transferred via pigged lines to their required destination.

Incorporating a high-pressure rinsing nozzle for cleaning the drums after use, and by automating the entire decanting process, ABB ensures reduction of waste by up to 90%, removing any residual quantity in the drums, minimizing cross contamination of pumped products and recycling effluents in the production cycle. ❐

A breakthrough in AI-enabled materials discovery

A groundbreaking artificial intelligence (AI) algorithm, dubbed CAMEO (Closed-Loop Autonomous System for Materials Exploration), rapidly identified a potentially useful new material — a germanium-antimony-tellurium alloy ($Ge_4Sb_6Te_7$) that is optimized for phase-change applications in data storage and photonic-switching devices. Tasked with evaluating 177 different materials, CAMEO performed 19 experimental cycles over ten hours, representing a nearly tenfold reduction in the time required compared to a scientist running the experiments in a laboratory. CAMEO is a self-learning AI, accessing and processing data from a combinatorial library of material compositions, using prediction and uncertainty to determine which experiments to run next. It then facilitates the experimentation procedures, such as x-ray diffraction (XRD), and collects the data. At this point, CAMEO can request additional information, such as data on a material's crystal structure, before running the next experiment. CAMEO contains knowledge related to previous simulations and laboratory experiments, equipment operation and physical concepts, such as phase mapping, or the behavior of atomic arrangement with changing chemical composition. Since the AI runs unsupervised, it enables scientists to more easily work remotely, an ability that is especially valuable for experiments involving potentially toxic chemicals or contagious viral media.

For CAMEO's recent breakthrough, researchers set out to determine the Ge-Sb-Te alloy that exhibited the largest difference in optimal contrast between the crystalline and amorphous states. In terms of optical contrast, the new alloy is twice as effective as a commonly used phase-change material, $Ge_2Sb_2Te_5$. To achieve this discovery, CAMEO focused on the material-structure-properties relationship of various crystalline materials, effectively tracking the structural origins of a material's function. Moving forward, researchers plan to make the algorithm capable of solving more complex problems. Several institutions contributed to the development and demonstration of CAMEO's recent achievement, including: the National Institute of Standards and Technology (NIST; Gaithersburg, Md.; www.nist.gov); Stanford University (www.stanford.edu); the University of Maryland (www.umd.edu); the University of Washington (www.washington.edu); and the U.S. Department of Energy (DOE; Washington, D.C.; www.energy.gov).

Membrane extraction improves biofuel yield

Typically, the production of fuel-grade chemicals, such as butanol, from biomass fermentation processes involves low-yield batch processes and high energy costs. Now, researchers from Imperial College London (ICL; www.imperial.ac.uk), in partnership with bp plc (London; www.bp.com), have demonstrated a new membrane-based extraction process for biofuels that helps overcome these hurdles, reportedly boasting a 25% reduction in energy use and a tenfold increase in production yield. In typical biomass fermentation processes, the produced butanol contains water that must be removed, either through heterogeneous distillation (requiring an energy-intensive phase change) or batch liquid-liquid extraction, explains Ji Hoon Kim, ICL researcher and co-author of the study. "Our new membrane-extraction process can extract the produced biofuel from a fermentation broth using an extractant with a high partition coefficient, providing high recovery rates through a membrane without requiring phase change," adds Kim. Since the extractant — an organic solvent based on 2-ethyl-1-hexanol — has around half the heat capacity of water and a higher boiling point than butanol, it does not require evaporating any water or extractant, meaning that the separation process requires significantly less energy. The ultra-thin-film composite membrane is highly selective for butanol, blocking the transport of water and extractant. Due to the extractant's fast recovery rate and high recovery capacity, the volume ratio of extractant to fermentation broth required to operate the system is very small, avoiding potential toxicity issues with the fermentation microorganisms.

Furthermore, since the membrane quickly extracts the butanol from water into the organic solvent, the butanol level in the fermentor is kept low, and microbes can remain more active, increasing productivity and enabling more streamlined, continuous operation, adds Andrew Livingston, ICL professor of chemical engineering and lead author on the project. The membrane extraction process has been demonstrated in the laboratory using a 2-L reactor, and Livingston says that the team is now looking at scaling up membrane production and investigating the effects of biofouling on the system. ■

Business News

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Plant Watch

LG Chem to run Wuxi cathode-materials plant on 100% renewable power

December 14, 2020 — LG Chem Ltd. (Seoul, South Korea; www.lgchem.com) concluded an agreement related to the supply of 140 GWh of renewable energy for its cathode-materials plant in Wuxi, China from local wind- and solar-power company Yunfengxin Energy. This 140-GWh capacity can supply all electricity required by the Wuxi facility annually. LG Chem's Wuxi plant is projected to operate solely using renewable energy beginning in 2021.

Mitsubishi Chemical acquires land in Louisiana for new MMA plant

December 10, 2020 — Mitsubishi Chemical Corp. (Tokyo; www.m-chemical.co.jp) acquired greenfield property at a large integrated site in Geismar, La. and plans to advance its feasibility study for the design and construction of a methyl methacrylate (MMA) plant with a production capacity of 350,000 metric tons per year (m.t./yr). The project is in the early engineering stage and is scheduled for final investment decision in early 2022. If approved, the plant would commence production in 2025.

Petrofac announces startup of Kuwait's largest crude distillation unit

December 10, 2020 — Petrofac Ltd. (St. Helier, U.K.; www.petrofac.com) announced that the Clean Fuels Project for Kuwait National Petroleum Co. (KNPC) has reached a major milestone with the successful startup of the crude distillation unit (CDU) at Mina Abdullah Refinery. With a petroleum-refining capacity of 264,000 barrels per day (bbl/d), it is the largest CDU in Kuwait.

Linde to construct oxygen plant at Metsä Fibre's new bioproducts plant

December 8, 2020 — Metsä Fibre Oy (Espoo, Finland; www.metsafibre.com) and Linde plc (Guildford, U.K.; www.linde.com) signed an agreement related to the construction of an onsite oxygen plant to supply Metsä Fibre's new bioproduct mill in Kemi, Finland. The new oxygen plant would be one of the world's largest units based on vacuum pressure-swing adsorption (VPSA) technology.

Sinochem starts up ethylene plant using KBR cracking technology

December 8, 2020 — KBR, Inc. (Houston; www.kbr.com) announced the successful startup of Sinochem Quanzhou Petrochemical Co.'s 1,000,000-m.t./yr ethylene plant in Quanzhou, Fujian Province, China. The ethylene plant is part of Sinochem Quanzhou's grassroots integrated petroleum-refining and petrochemical manufacturing complex.

Yara announces world-scale green ammonia project

December 7, 2020 — Yara International ASA (Oslo, Norway; www.yara.com) has announced plans to produce 500,000 m.t./yr of green ammonia in Norway. Yara is currently seeking partners and government support, and predicts that the project could be operational in 2026.

Lanxess expands production capacity for iron-oxide pigments

December 2, 2020 — Lanxess AG (Cologne, Germany; www.lanxess.com) expanded its capacity for black synthetic iron-oxide pigments at its Krefeld-Uerdingen, Germany site by more than 5,000 m.t./yr. The site's debottlenecking measures will position it to serve demand from the construction industry for black pigments.

Perstorp plans to build sustainable-methanol plant

November 24, 2020 — Perstorp AB (Malmö, Sweden; www.perstorp.com) has developed a new technology to produce methanol from a variety of recovered waste streams and hydrogen via electrolysis, aiming to substitute the 200,000 m.t./yr of conventional methanol that the company uses as a raw material for chemical products. The goal is to start producing sustainable methanol in 2025.

Arkema starts up expanded fluoropolymer capacity in China

November 24, 2020 — Arkema S.A. (Colombes, France; www.arkema.com) started up an expanded fluoropolymer production line at its Changshu, China plant, one of the company's largest sites. Serving the Li-ion-battery market, the new expansion raises production volumes for Kynar fluoropolymers by around 50%.

Mergers & Acquisitions

Trinseo to acquire Arkema's PMMA business

December 14, 2020 — Trinseo, LLC (Berwyn, Pa.; www.trinseo.com) agreed to acquire Arkema's polymethyl methacrylates (PMMA) and activated methyl methacrylates (MMA) businesses. The transaction is expected to generate approximately $50 million in annual cost synergies by 2023.

Mitsubishi Chemical to consolidate international subsidiaries

December 10, 2020 — Mitsubishi Chemical will integrate subsidiaries at the national level in the U.S., U.K. and Germany. Nine subsidiaries in the U.S. will be integrated into new company Mitsubishi Chemical America, Inc, which will be located in Charlotte, N.C. In the U.K., five subsidiaries will be combined into new company Mitsubishi Chemical UK Ltd., located in Billingham,

Cleveland, U.K. In Germany, five subsidiaries will be merged under the new integrated company Mitsubishi Chemical Europe GmbH, located in Düsseldorf.

Aramco and Baker Hughes form JV focused on non-metallic products

December 10, 2020 — Saudi Aramco (Dhahran, Saudi Arabia; www.aramco.com) and Baker Hughes (Houston; www.bakerhughes.com) established Novel, a 50/50 joint venture (JV) to develop and commercialize a broad range of non-metallic products. Initially, the JV is constructing a manufacturing facility that will produce non-metallic pipelines, including reinforced thermoplastic pipes (RTP) from composite materials.

Evonik acquires biodegradable polymers business from Durect

December 8, 2020 — Evonik Industries AG (Essen, Germany; www.evonik.com) signed an agreement to acquire the Lactel business of biodegradable polymers from Durect Corp. (Birmingham, Ala.) for $15 million. Lactel polymers are used in advanced drug delivery, biomaterials for tissue engineering and 3D-printed medical devices.

Huntsman acquires specialty-chemicals manufacturer Gabriel Performance Products

December 7, 2020 — Huntsman Corp. (The Woodlands, Tex.; www.huntsman.com) agreed to acquire Gabriel Performance Products, a manufacturer of specialty additives and epoxy curing agents. Under terms of the agreement, Huntsman will pay $250 million for Gabriel, including its three manufacturing facilities located in Ashtabula, Ohio, Harrison City, Pa. and Rock Hill, S.C.

LyondellBasell and Suez jointly acquire recycling business

December 7, 2020 — LyondellBasell N.V. (Rotterdam, the Netherlands; www.lyondellbasell.com) and Suez (Paris, France; www.suez.com) jointly acquired Tivaco, a plastics recycling company located in Blandain, Belgium. The company will become part of Quality Circular Polymers (QCP), the companies' existing JV. With this transaction, QCP will increase its production capacity for recycled materials to approximately 55,000 m.t./yr.

Solvay to sell barium, strontium and sodium percarbonate businesses

November 24, 2020 — Solvay S.A. (Brussels, Belgium; www.solvay.com) has reached an agreement with Latour Capital to sell its technical-grade barium and strontium business in Germany, Spain and Mexico, as well as its sodium percarbonate business in Germany. The completion of the transaction is expected in the first quarter of 2021.

Ineos to acquire Sasol's stake in Gemini HDPE business

November 24, 2020 — Ineos (London; www.ineos.com) agreed with Sasol Ltd. (Johannesburg, South Africa; www.sasol.co.za) to acquire Sasol's 50% membership interest in Gemini HDPE LLC for $404 million. Gemini is a toll manufacturer of bimodal high-density polyethylene (HDPE) products. ■

Mary Page Bailey

New Ways to Achieve Better Control of Emissions

New and improved catalysts and other process innovations are helping the chemical process industries (CPI) to control emissions

As long as fossil fuels are used for combustion processes — not only in power plants, but also furnaces in the glass and cement industries, boilers, steam reformers and others — the control of emissions from "traditional pollutants" will continue to be required. "NOx, SOx and H_2S are the 'bread and butter' for companies like ours," says Diego Tebaldi, general manager of the CR Clean Air Group LLC (Parsippany, N.J.; www.crcleanair.com). "There's always a strong demand and repeat business from old systems that need replacing or renewing.

CR Clean Air Group has thousands of installations across the world addressing these core contaminant applications," he says. The company designs and offers wet scrubbers, packed-tower scrubbers, and high-energy Venturi scrubbers to meet a variety of applications, ranging from arsenic and zirconium tetrachloride to chemicals like trimethylamine and dimethylamine, says Tebaldi (Figure 1).

Multiple pollutants

Meanwhile, GEA AG (Düsseldorf, Germany; www.gea.com) has been working to simplify the treatment of emissions-control processes, with the introduction of its BisCat ceramic catalyst candle-filter technology, says Andreas Palinski, vice president, GEA Bischoff GmbH (Essen, Germany) — the main and largest Emission Control Business unit of GEA. Initially targeting the glass and cement industries, BisCat combines the three process stages of de-dusting, separation of acid components and reduction of total hydrocarbons and oxides of nitrogen (NOx) in one unit (Figure 2). The system uses high-temperature filters with ceramic elements that enable the removal of NOx, dioxins, mercury and volatile organic compounds (VOCs) through an integrated catalyst matrix. BisCat ceramic catalyst filters are chemically inert and corrosion-resistant.

Particle separation takes place with the aid of filter elements made of mineral fibers. These ceramic candles are well proven and very flexible to use even with regard to modifications of operating parameters, especially at high gas temperatures. No cooling of fluegases is required and no thermal heat energy is wasted. Filter elements are cleaned from separated dust online during operation by means of separate, compressed-air jet pulses. The single or multi-sectional housings allow a maximum filter length of 6 m. Inorganic pollutants, such as HF, HCl and SOx can also be absorbed. Applications include the cement and glass industries, incinerators, petroleum refineries and roasters.

Haldor Topsoe A/S (Lyngby, Denmark; www.topsoe.com) has also been making progress on treating multiple pollutants. The company's SNOX fluegas-desulfurization (FGD) process removes SO_2, NOx and particulate matter from fluegas. The sulfur is recovered as commercial-grade concentrated sulfuric acid and the NOx are reduced to free N_2. The catalytic process does not consume water or adsorbents, and generates no waste except the separated dust.

The SNOX process includes the following steps: dust removal; catalytic reduction of NOx by adding NH_3 to the gas upstream from the selective-catalytic reactor (SCR); catalytic oxidation of SO_2 to SO_3 in the oxidation reactor; and cooling of the gas to about 100°C whereby the H_2SO_4 condenses and can be withdrawn as a concentrated sulfuric acid product.

FIGURE 1. This two-stage scrubber system that addresses dimethylamine and trimethylamine emissions is shipping to the Philippines from CR Clean Air Group's New Jersey site

Last April, the Thai Oil Public Company Ltd. (Thaioil; www.thaioilgroup.com) signed an agreement for Topsoe's SNOX process to remove sulfur, NOx and dust emissions from its Sriracha Refinery in the Chonburi province in the east of Thailand. This is part of Thaioil's $5-billion Clean Fuel Project to produce cleaner transport fuels in a more environmentally friendly way. The Sriracha Refinery's new energy recovery unit will use three parallel SNOX lines to remove SOx, NOx and dust from the new circulating fluidized-bed boilers.

FIGURE 2. BisCat technology uses catalyst-loaded ceramic candles to treat multiple pollutants in a single unit

Sulfur emissions

Another focus of GEA is to recover valuables out of waste gas streams, explains Palinski. "By achieving much lower emission values through more efficient gas-cleaning devices, the concentration and quality of the eliminated substance is becoming much higher and allows users to sell the product at better prices, for example sulfuric acid with a high purity," he says. The company will soon introduce its new, more-efficient Linear Flow Scrubber to meet these trends.

Last August, Haldor Topsoe and Comprimo — part of Worley (North Sydney, NSW, Australia; www.worley.com) formed a strategic alliance to jointly license TopClaus, a sulfur removal and recovery technology. TopClaus integrates two industry-proven technologies: Topsoe's proprietary Wet-gas Sulfuric Acid (WSA) process and Comprimo's Claus process, enabling users to achieve more than 99.9% sulfur-removal efficiency (SRE). The combination is also said to have a "significantly lower" cost-of-ownership compared with traditional technologies, such as a Claus unit followed by a conventional amine-based tailgas-treatment unit, says the company.

The Claus part of the TopClaus solution recovers elemental sulfur from acid gases. The tail gases from the Claus unit are then treated in the WSA unit, where the remaining sulfur compounds are converted into sulfuric acid. The sulfuric acid is returned directly to the Claus reaction furnace for reprocessing to elemental sulfur, with no sulfuric acid left as byproduct. However, sulfuric acid can be drawn off for specific uses or for sale as desired.

TopClaus also significantly reduces a petroleum-refinery's CO_2 footprint because it eliminates the need to incinerate tailgas. In addition, the WSA unit recovers as much as 90% of the process heat as valuable, superheated, high-pressure steam. The steam can be used in other refinery processes or for generation of electricity. This results in much lower operating costs compared to any conventional amine-based technology that uses steam for amine regeneration and requires tailgas incineration.

Meanwhile, Frames Group B.V. (Alphen aan den Rijn, the Netherlands; www.frames-group.com) announced last November that it supplied and commissioned a H_2S-removal unit to a petroleum refinery in Antwerp, Belgium. The unit uses Frames' proprietary Laminol technology, which is said to have "significantly lower cost of ownership" than conventional caustic scrubbers and solid-bed type H_2S-removal processes.

Instead of treating the fluegas directly, the Laminol technology removes sulfur components from

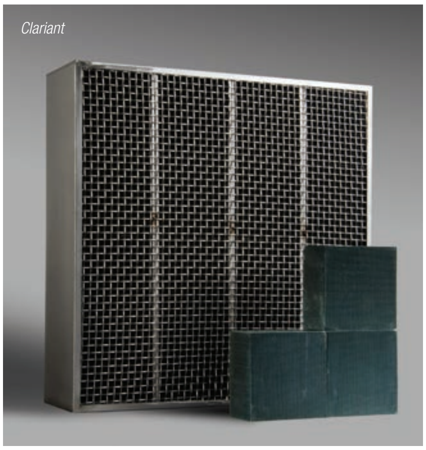


FIGURE 3. Clariant's EnviCat VOC catalyst is being used to control emissions at a phthalic anhydride plant in China

Yokogawa Corporation of America

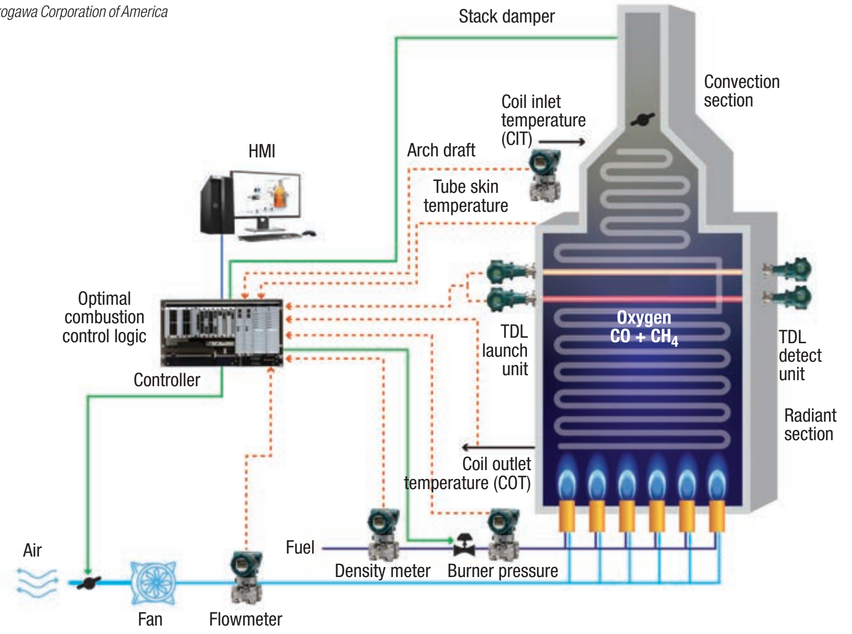


FIGURE 4. CombustionONE is a comprehensive and collaborative approach to fired asset management that includes an engineering analysis of the fired asset and the resolution of performance and safety issues by the strategic application of hardware, software and turnkey project services with a quantifiable return on investment

the distillation overhead gas containing up to 60% H_2S before it is combusted in the process furnace. Treating the waste gas in a standalone modularized unit meant that the unit was much easier to integrate into the existing refinery facility, says the company. The gaseous sulfur removed is converted into elemental sulfur in solid form.

"Laminol is a highly effective, and economically attractive, method for deep H_2S removal at high concentrations," says Lennard Spit, gas treatment specialist, Frames. "And unlike many other removal systems, the technology is robust and capable of infinite turndown and handling feed-gas fluctuations that are more representative of 'real world' refinery waste streams."

Frames' Laminol technology is the result of an in-house R&D program initially developed and applied in the biogas market where it provides a cost-effective alternative to conventional biogas sweetening processes. The Laminol technology is capable of selectively removing H_2S from CO_2-rich gas streams to a few parts per million (ppm) even at near atmospheric gas pressure and is suitable for treating any gas stream.

Chemical emissions

"Lately we have seen an area of further attention, which is more focus and activity to do with ethylene oxide and propylene oxide (EO/PO) contamination," says Clean Air Group's Tebaldi. "The company has one of the leading install bases for this, and we've seen renewed interest from existing and new customers as there are discussions about tightening regulations."

"Our primary R&D [research and development] focus this year (2020), which will become operational in Q1 2021, is an improvement to the current handling of ethylene oxide and propylene oxide (EO/PO)," continues Tebaldi. Essentially, most uses of this come from either chemical process, medical sterilization or production. "Our current systems achieve 4-nines or even 5-nines removal rates with ease when it's at high concentration, but we've noticed as regulations tighten, we're seeing applications where a high level of CFM [cubic feet per minute] and very low level of contamination are prevalent. We're close to finalizing a system that addresses that economically. All current systems, including ours, become economically unfeasible when you have over 10,000 ACFM [actual CFM] of flow, with low concentration levels. CR Clean Air Group is excited to help our customers address this particular need with our new systems in 2021. Once commercial, we'll look at NOx and other areas for improvements," he says.

Meanwhile, Clariant Catalysts (Munich Germany; www.clariant.com) has been expanding the applications for its EnviCat VOC catalyst (Figure 3). The company recently announced that the catalyst has been operating successfully since November 2019 at the phthalic anhydride (PA) plant of Shandong Qilu Plasticizers Co. Ltd., located at Zibo, Shandong province, China. The unit combines the catalytic combustion unit of Jiangsu Jinneng Environmental Science and Technology with Clariant's EnviCat VOC catalyst to purify production offgas, which contains VOCs and carbon monoxide.

Clariant's extensive experience in off-gas treatment catalysts has resulted in the development and widespread use of its high-performance EnviCat VOC. The catalyst is proven to effectively remove both VOCs and CO with an excellent conversion efficiency of up to 99% and above. It operates at up to 400°C lower temperatures compared to other off-gas purification methods, such as recuperative thermal oxidation. This greatly reduces fuel consumption and equipment stress, leading to potential significant economic, operational, and safety advantages, says Clariant.

"Jiangsu Jinneng and Clariant have collaborated in off-gas treatment in China for over 10 years. We strengthen each other's advanced technologies to offer each plant operator the ideal solution for their company and the environment," says Chen Min Dong, general manager at Jiangsu Jinneng.

China's 13th Five-Year Plan has set ambitious targets for decreasing air pollutants, including a 10% reduction of VOCs.

Improving efficiency

"The biggest upcoming megatrend is CO_2 reduction by energy saving, such as using waste heat recovery," says GEA's Palinski. "In many industrial processes, thermal energy is released to the atmosphere unused and this so-called 'waste heat' can be made available by a waste-heat-recovery system (WHRS), and utilized for different purposes, such as electric power generation via an ORC (organic Rankine cycle)," he says.

According to Eric Meyer, Combustion Solutions consultant at Yokogawa Corporation of America (Sugar Land, Tex.; www.yokogawa.com/us), CO_2 has been categorized as a pollutant due to the potential as a greenhouse gas. As such, most European countries have adopted carbon taxes ranging from under $1 per ton to over $100/ton. Canada has also adopted a carbon tax that will be $40/ton in 2021. The U.S. does not currently have a nationwide carbon tax but a few states have cap-and-trade schemes, says Meyer.

Large consumers of fossil fuels are looking to reduce their carbon footprints by improving process efficiency, reducing fuel consumption, improving use of waste fuels or by broadening their portfolios to include carbon-free production methods. Improving combustion in large consumers of fossil fuel can lead to a great deal of fuel savings, as well as a reduction of the carbon footprint, explains Meyer. If done properly, it can also lead to improved specific consumption for that unit. For example, the fuel savings that results from just 1% less stack oxygen in a typical steam methane reformer (SMR) can exceed $1 million year-over-year, and the reduction in carbon emissions would be over 27,000 tons per year. In Canada, that would be worth another $1 million per year in carbon tax. "The good news is that we typically see a sustainable improvement that is two to three times as much," claims Meyer.

Yokogawa has a unique technology, CombustionONE (Figure 4), which can help fossil fuel consumers reduce fuel consumption, reduce carbon footprint, improve process stability, utilize waste fuels better, improve catalyst life and improve tube life. This is accomplished by an in-depth analysis of the furnace, resolution of issues that will prevent sustainable operation, and the application of improved instrumentation such as tunable-diode-laser spectrometers (TDLS). A TDLS allows rapid analysis of excess O_2 and CO, realtime measurements of fuel density and combustion air flow, and the application of improved control logic. The result is sustained operation at 1% excess O_2. "This is in stark contrast to the operation prior to the application of the solution, where we have seen excess O_2 levels in the range of 3 to 7%," says Meyer. ■

Gerald Ondrey

Flow Measurement & Control

Endress+Hauser

Krohne

Fluid Components International (FCI)

Flowmeter with pressure and temperature sensors, too

The Proline Prosonic Flow G flowmeter (photo) can be supplied with either of two different transmitters (photo): as a compact version (Proline 300), or as a remote version (Proline 500) with up to four inputs and outputs. These inputs and outputs provide flexibility, with the ability to output not only flow, but also pressure, temperature and numerous other process variables. This flowmeter measures both dry and wet gases with high precision (±0.5%), repeatability, and high reliability — even when process and ambient conditions fluctuate significantly. The meter operates at process temperatures up to 150°C (302°F) and pressures up to 100 bars (1,450 psi), and can be ordered with built-in pressure and temperature sensors. The input from these sensors can be combined with the measured sound velocity to calculate additional gas properties, which are often important for process control. Some examples are volume flow, corrected volume flow, mass flow, energy flow, calorific value, Wobbe index, gas type, molar mass, methane content (%) and density or viscosity. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

A new design for cost-effective flow measurement

The new Optisonic 6300 V2 ultrasonic flowmeter features a stationary, clamp-on design. The Optisonic 6300 V2 allows users to measure flow anywhere necessary, all while processes continue operating. New to the Optisonic 6300 V2 are the following: the ability to handle a viscosity range of up to 200 cSt; there is no need for re-greasing due to solid coupling material; a next-generation signal converter for enhanced application range; Namur NE107 diagnostics; and integrated thermal energy calculation. The device is suitable for diameters ranging from ½ to 160 in. It handles a process temperature range of –40 to 392°F (–40 to 200°C). The flowmeter is constructed as a submersible stainless-steel sensor rail (IP 68/NEMA 6P). For the complete diameter range, the Optisonic 6300 V2 offers flexible configurations: single and dual ultrasonic sensors; wall and field signal converter housing; and V-, W-, Z-, and X-mode measurement configuration. — *Krohne, Inc., Beverly, Mass.*
www.us.krohne.com

This thermal mass flowmeter has ATEX/IECEx approvals

ATEX and the IECEx approvals assure that the ST80 Series thermal mass flowmeter (photo) has been independently certified for safe installation in potentially explosive conditions found in processes and in hazardous-gas flowmetering applications. The independent third-party testing and certified ratings of the ST80 cover the complete instrument, including the sensor element, electronics and the enclosure. The ST80 Series meters are suitable for pipe diameters from 1 to 99 in. (25 to 2,500 mm) and air/gas temperatures up to 850°F (454°C). They have an accuracy of ±1% of reading, ±0.5% of full scale and repeatability of ±0.5% of reading with flowrates up to 1,000 std. ft^3/s (305 Nm^3/s) and 100:1 turndown. The ST80 Series uses the company's patent-pending Adaptive Sensing Technology (AST) thermal mass-flow-measuring technique, which include a hybrid sensor drive plus measuring circuit that combines both proven thermal dispersion techniques of constant power (CP) and constant temperature (CT) in the same instrument. The ST80 with AST measures in CT mode when measuring in lower flow ranges and start-up conditions, and will transparently and seamlessly shift to CP mode at mid-range and higher flowrates. — *Fluid Components International (FCI), San Marcos, Calif.*
www.fluidcomponents.com

Mass flowmeter certified for hydrogen filling stations

This company has developed the TMU-W 004 mass flowmeter (photo, p. 17), which ensures precise metering despite pressure and temperature fluctuations. The device is said to be the first of its kind certified to international standard OIML R 139 2018, and thus approved for H_2 filling sta-

tions. A robust, slender housing protects specially arranged sensors and measuring loops that use the Coriolis effect and enable very precise flow measurement. The attached transducer converts the sensor signals into a reading that can be used to further analyze the flowrate. At the same time, the meter measures the temperature of the medium. The TMU-W 004 is suitable for high-pressure applications up to 1,000 bars. The meter ensures that during filling, the amount of hydrogen transferred to the vehicle tank is measured accurately. This enables correct billing of the amount filled, which is a prerequisite for fueling at public H_2 filling stations. It covers a measurement range of 0.133 to 4 kg/min of H_2. — *Heinrichs Messtechnik GmbH, Cologne, Germany*
www.heinrichs.eu

Monitor and control three variables with a single sensor

With the PF55S and PF75H/S electromagnetic flowmeters (photo), it is possible to measure volumetric flow, flow velocity and temperature — three of the most important variables that help to ensure efficient process control. Designed for industrial applications, these compact flowmeters are suitable for applications with high flow velocities up to 10 m/s, with the PF75H/S capable of measuring media with a conductivity of 5 µS/cm and available in a hygienic or a robust industrial design. Thanks to the design of these electromagnetic flow sensors, precision combined with long-term stability and reliable measurement is assured with accuracy of up to 0.2%. The combination of precise measurement of volumetric flow and flow velocity means that tasks such as volume balancing, mixing and dosage processes can be optimized and controlled very accurately. The result is the use of valuable resources, such as liquid foods, chemicals or fresh water can be minimized, helping to save energy, generating less waste and reducing costs. — *Baumer Ltd., Swindon, U.K.*
www.baumer.com/gb/en

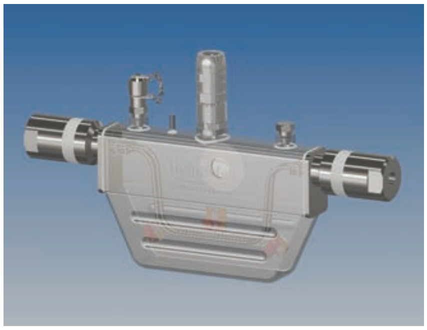
Flowmeters that Install on the outside of pipes

This new series of Clamp-On Ultrasonic Flow Meters (photo) fasten onto the outside of vertical or horizontal pipes ranging in size from ½ through 48 in. Housed in a water- and dust-tight NEMA 4X polycarbonate enclosure, the Clamp-On Ultrasonic Flow Meters are compatible with a range of metal and plastic pipe materials and "difficult liquids," such as viscous chemicals and abrasives that would damage standard flowmeters. The non-intrusive sensors deliver enhanced flow measurement with no pressure drop in a range of applications, such as food or chemical processing plants, petroleum refineries and more. Operating from 100 to 240 V a.c., the flowmeters offer an isolated 4–20-mA output that can transmit flow readings to remote displays, recorders or controllers. A 128-MB data logger is standard, capable of capturing up to 26 million data points. Optional Modbus RTU via RS-485 or HART communication protocols are available for connection to automation systems. — *AW-Lake Co., Oak Creek, Wis.*
www.aw-lake.com

This flowmeter is accurate — even for short pipe runs

The full-bore, Signet 2580 FlowtraMag magnetic flowmeter (photo) is designed for high-accuracy flow measurement in short pipe runs. High accuracy is achieved for these problematic runs with a new sensor design that has shorter inlet and outlet pipe lengths, and certified factory calibration. All thermoplastic construction provides superior corrosion resistance for long, maintenance-free service life. Available in pipe sizes of 1-, 2- and 4-in. PVC (polyvinylchloride) Schedule 80, the FlowtraMag is two to three times lighter in weight compared to traditional metal magmeters on the market. The unit offers accuracy of ±1% of reading and repeatability of ±0.5%. Streamlined monitoring and complete versatility is provided via the meter's broad communications capabilities across multiple platforms. These include digital (S3L), frequency, and active or passive analog 4–20 mA. Visual LED indicators make sensor status clear and easy to read. Unlike other meters that can only connect to flanges, the 2580 can connect to union ends in sizes 2 in. or less, and flanges in 4 in. — *Georg Fischer LLC, Irvine, Calif.*
www.gfps.com

Heinrichs Messtechnik



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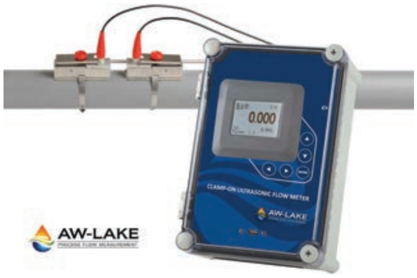
AW-Lake



George Fischer

Flow Technology

Flexim

Emerson

In-line flowmeters for low-viscosity fluids

The QCT Series of inline ultrasonic flowmeters (photo) is a compact, versatile, cost-effective solution for measuring low-viscosity liquids in the chemical process industries (CPI). The meter's construction makes it suitable for many high-purity and corrosive fluids. Typical applications include water treatment for boilers and cooling towers, clean-in-place (CIP) systems, mechanical seal flushing/cooling, high-purity water systems, process water, cooling loops, reverse-osmosis (RO) systems, and small-line injection systems. High accuracy and repeatability are achieved through the unique measurement section within the QCT Series meter where flow is conditioned and temperature differential measured along the meter's axis. The QCT has no moving parts or non-wetted sensors, and there is nothing in the flow stream that will cause an obstruction to the flow path. The meter is available in sizes of 1/8 to 1 in., and is accurate to ±0.5% of reading, plus zero stability and repeatability is ±0.2% over 10:1 calibration range. It has a flow range of 0.035 to 70 gal/min, a temperature range of –10 to 80°C and analog, scaled frequency and Modbus RTU outputs. — *Flow Technology, Inc., Tempe, Ariz.*
www.ftimeters.com

Measure flow of high-temperature steam

Fluxus ST-HT (photo) is said to be the world's first and only clamp-on ultrasonic flowmeter for high-temperature steam. The new measuring system has been designed to precisely record volume and mass flowrates of saturated and superheated steam at temperatures up to 400°C. Fluxus ST-HT measures steam flow non-invasively from the outside of the pipe. Non-invasive steam flow measurement means measuring without any interruption of operation or supply. Since clamp-on ultrasonic transducers are simply mounted on the outside of the pipe, it requires minimal installation effort and no pipeline penetrations. The acoustic measuring method has exceptionally high measuring dynamics and functions independently of the flow direction. The Fluxus ST-HT offers precise bidirectional flow measurement over a wide turndown ratio up to 25:1. The new Fluxus ST-HT is complementary to this company's existing steam flowmeter Fluxus ST, which has been brought to market also as a world-first last year and whose application range is limited to temperatures up to 180°C. Now, the new Fluxus ST-HT can be applied for steam measurements up to 400 °C in pipes up to 900 mm in diameter. This important extension of the application range has been achieved by the combination of the company's patented WaveInjector technology with the cross-correlation measuring method. — *Flexim GmbH, Berlin, Germany*
www.flexim.com

Flowmeter delivers accuracy and stability for H_2 applications

The new Micro Motion Coriolis flowmeter (photo) is designed for high-pressure hydrogen-dispensing and chemical-injection applications, where measurement accuracy and safety are essential. The Micro Motion Coriolis HPC015 flowmeter is capable of a flow-accuracy margin of 0.5% for gas and 0.1% for liquid mass-flow measurement, a significant improvement over existing meters, says the company. The meter performs under wide pressure and temperature fluctuations, ensuring security and reliability, while onboard diagnostic tools eliminate the need for pre-inspections or interim maintenance checks, saving time and money. One of the main applications for the HPC015 is to manage costs in large-scale custody-transfer applications, such as public transportation systems. A second, significant market for the HPC015 is in other high-pressure applications, such as injecting methanol, corrosion inhibitors and other chemicals downhole at high pressure. The HPC015 is designed to accurately and reliably dose chemicals at pressures up to 1,060 bars (15,374 psi) to ensure pipeline integrity and avoid events like plugging, which can halt production. — *Emerson, St. Louis, Mo.*
www.emerson.com ■

Gerald Ondrey

New Products

Optimize industrial training with immersive virtual reality

This company's Immersive Field Simulator (photo) is an advanced industrial-training solution that combines 3D immersive technology with operator-training simulation to create a collaborative learning environment for plant operators and field technicians. The system provides virtual reality (VR) and mixed reality tools that incorporate a digital twin of the physical plant to provide targeted, on-demand, skill-based training for workers. The system offers a smooth, virtual walkthrough to familiarize workers with the plant. It includes avatars that represent virtual team members. The simulator's cloud-hosted, device-agnostic platform, which incorporates flexible 3D models, grows with the user as plant operations change. The simulator is customizable to meet specific instructional needs, and project team members can easily create customized training modules. — *Honeywell Process Solutions, Houston*
www.honeywellprocess.com

A sanitary rotary mixer that is washdown-rated

The Model MX-5-S316L sanitary rotary-batch mini-mixer (photo) can de-agglomerate and blend up to 5 ft^3 of dry bulk ingredients with or without liquid additions at multiple plant locations. The mixer achieves total uniformity in 2 to 3 min, regardless of disparities in the bulk density, particle size, flow characteristics or ratio of batch ingredients down to one part per million (ppm). For dry materials, the mixer is equally efficient down to 15% of rated capacity, satisfying varied production requirements, while allowing for small-scale testing prior to blending at full capacity or scaling up to high-capacity rotary-batch mixers. The mixer is equipped with a product inlet slide for ease of feeding from bags or boxes, and an inlet-mounted spray line that allows liquid additions to be spread over a wide bed of moving material in large or trace amounts for rapid, uniform distribution. Blended batches are discharged completely through a breach-lock plug gate with no segregation or residual waste. The unit's gears are washdown-rated and are adjusted by variable-frequency controls housed in a NEMA 4X (IP 66) stainless-steel washdown enclosure. — *Munson Machinery Co., Utica, N.Y.*
www.munsonmachinery.com

A reliable and versatile pneumatic pressure controller

PMT Model 40 pneumatic pressure controllers (photo) are available in standard control modes of 100% proportional, 200% proportional, 200% proportional plus reset, 75% proportional (positioner only), or 300% PID (proportional-integral-derivative). These options make the controllers versatile enough to fit into almost any application. In addition to working as a pressure controller, the PMT Model 40 is also available as an indicating pneumatic transmitter. Mounted close to the measurement point, it transmits an air-pressure signal proportional to the measured variable to another indicator, recorder or controller. The Model 40 pressure controller is available in automatic and manual switch options and contains pre-calibrated elements for quick-field changes. — *Ametek Sensors, Test & Calibration (STC), Horsham, Pa.*
www.ametekstc.com

New high-volume granulation equipment improves yield

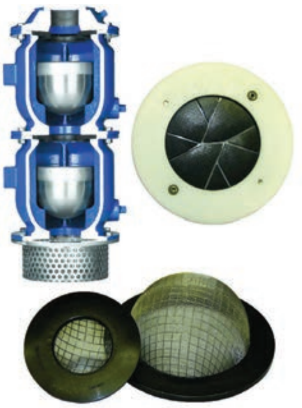
By combining the HSM 2000 X.ONE high-shear mixer and FBE 1800 X.ONE fluidized-bed units, this company has introduced the new GT 1600 X.ONE (photo), an advanced granulation system for high-volume batch production. The GT 1600 X.ONE eliminates some of the shortcomings of conventional granulation approaches, such as large equipment footprints, long processing times and low yields. The GT 1600 X.ONE features an efficient Z-shaped impeller to ensure optimum material flow and improved uniformity. To assist with effective discharge and cleanability, a compressed-air system enhances the reliability of the discharge valve seal, and a bag-type mechanical shaking filter on the fluidized bed offers a more effective product retention and higher yields compared with alternative blow-back style systems. Transfer of the wet granulated material into the fluid-

Honeywell Process Solutions

Munson Machinery

Ametek Sensors, Test & Calibration (STC)

ACG Engineering



Val-Matic Valve & Manufacturing

Readco Kurimoto

Monitor Technologies

ized bed is also optimally configured through the selection of a tangential charge port, ensuring effective product transfer and a consistently repeatable drying operation. — *ACG Engineering, Piscataway, N.J.*
www.acg-world.com

Protect potable water with this diverse product family

The VaultSafe product line (photo) is designed to protect potable water systems from contaminated floodwaters, freezing temperatures and intentional harmful contamination. The VaultSafe family consists of the FloodSafe inflow preventer, the FrostSafe air damper and the VentSafe vent-pipe security cage. The FloodSafe prevents contaminated water from passing through, thus preventing it from entering the air valve outlet and compromising the potable water system with its dual chambers and float checks. The FrostSafe minimizes the thermal exchange of cold and warm air in and out of a vault to help prevent freezing with a bi-directional hinge-less disc and wafer design. The VentSafe safeguards vent pipes against the hazards of nesting animals and intentional harmful activities because of its hemispherical screened security cage. Furthermore, this company's AWWA C514 inflow preventers can be applied to new or existing air valves and reservoir vents to substantially mitigate other threats to potable water systems. — *Val-Matic Valve & Manufacturing Corp., Elmhurst, Ill.*
www.valmatic.com

Achieve repeatable reactions with this one-step solution

This company's Continuous Hybrid Reactor (CHR; photo) has been designed to facilitate safe, efficient, repeatable chemical reactions. The CHR features a proprietary design that develops a deep vacuum to promote a high level of control over heat-transfer rate, residence time, mixing intensity and other reaction conditions. The CHR performs heating, cooling, mixing, degassing and other processes in a single step, automatically transforming liquids into powders or high-viscosity slurries, and powders or pellets into high-viscosity slurries or pastes. Suitable for processing elastomers, adhesives, sealants and other temperature- or oxygen-sensitive materials, the CHR feeds primary liquid, slurry or melted solid reactants, catalysts and other reagents through an injection port in the barrel. The integrated heating and mixing action drives the reaction during retention times of up to 1 h, or longer as needed. Consistent product quality is assured while any vapors, volatiles or particulate matter are eliminated, reduced or safely filtered and reused or removed. — *Readco Kurimoto, LLC, York, Pa.*
www.readco.com

These dust monitors now have hazardous-location approvals

The DustAlarm ES and DustTrend ES series (photo) of broken-bag detectors and dust-emission trend-monitoring systems are now available with hazardous-location approvals. The devices feature intrinsically safe probes for ultimate hazardous-location protection. These monitors provide repeatability that is not affected by variations in relative humidity, process temperature or pressure. These units are appropriate for monitoring the level of dust emissions in dust-collection system exhausts in any location where such information is critical to safety, maintenance, equipment operation, plant efficiency, employee welfare and the environment. The monitors can be connected with the free DustConfig software to set custom alarm points, view live activity within the duct, or review data history for up to a 24-h period. — *Monitor Technologies LLC, Elburn, Ill.*
www.monitortech.com

Cr-free corrosion inhibitors provide long-lasting protection

This company's chromium-free corrosion-inhibiting technology, Intelli-ion, utilizes novel active ingredients, which are attached onto a smart micro-reservoir system and react "on demand" to corrosive activity. Unlike zinc phosphate, which causes harmful algal blooms through leaching, the Intelli-ion product range does not leach out into the environment. The Intelli-ion technology protects metal assets when used in primers and meets the strictest environmental standards and requirements. The anti-corrosive materials are said to protect metals for

up to ten times longer than alternative products via three modes of electrochemical protection. The protection response is fast and highly effective: pigments lay dormant in the micro-reservoir system until they can sense corrosion activity and subsequently release the inhibitor on demand. The system is also non-encapsulated, allowing greater flexibility and performance when working with ultra-fine particle sizes. — *Hexigone Inhibitors Ltd., Port Talbot, U.K.*
www.hexigone.com

Thermal and visible videoscope for underground utility vaults

The new FLIR VS290-32 (photo) is said to be an industry-first videoscope that combines thermal imaging and a visible camera designed for safer and more efficient inspections of hard-to-reach areas. The VS290-32 is the company's first industrial-grade, electrical safety-rated, flexible dual-sensor videoscope on a replaceable, 2-m-long camera probe. For use in the most demanding environments, the VS290-32 is CAT IV 600 V safety rated for electrical inspections, along with an IP67-rated camera tip and IP54 base unit to protect against dust and water. The device features this company's patented Multi-Spectral Dynamic Imaging (MSX), which improves image clarity by embossing visual scene details onto full thermal images, providing crucial context to accurately and safely assess and identify potential issues to prevent blackouts and asset failures. A low-profile tip and bright LED worklight provide illumination for MSX in dark environments, including in tight spaces within HVAC systems and inside machinery. — *FLIR Systems, Inc., Arlington, Va.*
www.flir.com

FLIR Systems

This IBC now also has FM approval

The Ecobulk SX-D intermediate bulk container (IBC; photo) is specially fitted with a steel hull to provide exten-

Schütz

Pfeiffer Vacuum

Wika Alexander Wiegand

Siemens Digital Industries

R. Stahl

sive protection against fire and also withstand extreme conditions. In the event of a fire, the steel containment basin prevents flammable contents from leaking and significantly reduces the spread of fire. This IBC significantly reduces risks by providing double leakage protection for sensitive, hazardous products. This container is said to be the first composite IBC to be awarded the "FM approved" certification seal by the FM Global Group. The approval, which is based on the internationally recognized industrial property insurer's FM 6020 test standard, applies to flammable and combustible liquids with a flashpoint of ≥ 37.8°C. — *Schütz GmbH & Co. KGaA, Selters, Germany*
www.schuetz.net

A new turbopump for ion-implantation applications

HiPace 2800 IT (photo) is a turbomolecular pump especially dedicated for ion-implantation applications. The rotor design of the turbopump results in an optimized pumping speed for light gases. This ensures very good process adaption for ion-implantation processes, where hydrogen is the gas most likely to accumulate. The pump has a pumping speed of 2,600 L/s for hydrogen. An intelligent temperature-management system prevents process condensation and deposition inside the pumping system. It allows users to set the temperature individually to support the process. — *Pfeiffer Vacuum GmbH, Asslar, Germany*
www.pfeiffer-vacuum.com

A needle valve for high-pressure applications

This company's new high-pressure needle valve (HPNV; photo) is designed for four pressure ranges of up to 15,000, 20,000, 30,000 and 60,000 psi. The sensitive components (spindle tip and sealing) are made of suitably resistant materials. Furthermore, the HPNV has the same characteristics as the company's other needle valves: low-wear operation due to the non-rotating spindle tip, smooth handling with low torque and leak tightness tested to BS6755/ISO 5208 leakage rate A. — *Wika Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.de

An industrial edge platform for data processing

With the new Industrial Edge Management system (photo), users can remotely monitor the status of every connected device and remotely install edge applications (apps) and software functions on distributed edge devices. In combination with existing hardware and software products, this Industrial Edge V1.0 open platform provides users with a ready-to-use and seamless solution for data processing on the production level with integrated device and app lifecycle management. With the new Industrial Edge Management system, distributed edge devices and their states can be monitored centrally, diagnosed, and managed by IT administrators and manufacturing engineers. This means that new software apps can be rolled out company-wide and securely on all connected Industrial Edge devices. — *Siemens Digital Industries, Nuremberg, Germany*
www.siemens.com

Explosion-protected products are now CCC-compliant

To secure access to the Chinese market, this company has obtained the China Compulsory Certification (CCC) for its product groups that are subject to this directive. This means that the company can continue to export its range of explosion-protected products to China with no restrictions and allows them to be implemented in customer-specific explosion-protection solutions at industrial sites in China. The CCC directive is comparable to the European new legislative framework for standardizing product quality. CCC certificates are issued by authorized test bodies. Since October 2020, the scope of the directive has been expanded to include a number of explosion-protected devices, which would no longer be allowed to be imported into China or put into circulation in China without corresponding Ex and CCC markings. Among other articles, this new regulation affects explosion-protected motors and pumps, power distribution boards, control and terminal boxes, operating terminals (photo), fieldbus systems and other automation products. — *R. Stahl AG, Waldenburg, Germany*
www.r-stahl.com

Purify complex bio-based solutions with these new resins

Lewatit PH 1074 HEP (photo) is the newest product in this company's portfolio of ion-exchange resins for the pharmaceutical and bioprocessing industries. In addition to the decolorization of fermentation broths and sugar solutions, the new resin is particularly suited to the purification and intermediate storage of heparin. The macroporous, strongly basic anion-exchange resin, which meets food-quality standards, is based on a cross-linked polyacrylate. It has a special pore structure and resin matrix, which has been exclusively developed for the capture of high-molecular-weight compounds. Lewatit PH 1074 HEP is suitable for the treatment and purification of products derived from biomass, because it supports the reliable capture and removal of organic substances with a high molecular weight. This means that liquid sugar syrups or complex process solutions, such as fermentation broths, for example, can be purified and treated. The macroporous structure and special polymer matrix of the new Lewatit PH 1074 HEP help achieve optimum adsorption capacity and desorption properties. This is advantageous in the recovery of high-molecular-weight hydrophilic anionic organic substances. — *Lanxess AG, Cologne, Germany*
www.lanxess.com

Lanxess

New cleaning agent rapidly breaks down fats and greases

Pure-OX FOAM (photo) is a peroxide-based foaming detergent specifically formulated for tough organic soils on equipment or floors, walls, ceilings, shelves and other surfaces. With the self-foaming characteristics of peroxide, Pure-OX FOAM provides both cleaning power and convenience. Once the powerful oxidation reaction is complete, the degradation products are oxygen and water, so Pure-OX FOAM will not add salt or conductivity to water discharge, nor will it impact wastewater pretreatment operations. Ideal for foam cleaning, it readily breaks down proteins, fats, greases, oils and other organic soils. All ingre-


Madison Chemical


Terracon


Rockwell Automation


Gericke USA

dients in Pure-OX FOAM are GRAS (generally recognized as safe) or have prior-sanctioned FDA approval for direct or indirect incidental food contact. This chlorine-free, high-foaming cleaning product is noncorrosive to aluminum and stainless steel when used as directed. Before using Pure-OX FOAM, food products and packaging materials must be removed from the room or carefully protected. After use, all surfaces in the area must be thoroughly rinsed with potable water. — *Madison Chemical, Madison, Ind.*
www.madchem.com

Customizable mobile totes for biopharmaceutical applications

This company has introduced the KDT series of configurable knockdown mobile totes (photo) for the storage, holding or transfer of fluids in life science and biopharmaceutical applications. KDT mobile totes are suitable for solution preparation, storage and transport, bulk harvest, product pooling and bulk intermediate-hold applications. They are manufactured under an ISO 9001 quality-management system for cleanroom use, and their all-plastic, USP Class VI construction meets cGMP and FDA requirements. The totes come in 100- to 500-L sizes and they are easily bundled with single-use bags, tubing, pumps and other accessories. The KDT knockdown mobile totes feature fast, simple assembly and positive-lock bottom drains for most bag brands. The totes' flat, smooth surfaces limit mold crevices and enable easy cleaning. Their self-contained knockdown design permits tote storage in its own base. Furthermore, the units are stackable to maximize footprint utilization in-use or stored. — *Terracon Corp., Franklin, Mass.*
www.terracon-solutions.com

New industrial PCs create a secure visualization system

The Allen-Bradley VersaView 6300 PCs and thin clients (photo) combine with this company's FactoryTalk View human-machine interface (HMI) software and ThinManager thin-client management software to create a complete visualization system. For mission-critical applications, users can deploy ThinManager redundancy or a VersaView 6300 PC running local and remote applications to help ensure reliability if server communications are lost. In addition, unlike most industrial PCs, each model in the VersaView 6300 family is individually designed to minimize or remove frequent points of failure like fans and connectors, helping reduce costs and extend the life of the PC, says the manufacturer. The new Allen-Bradley VersaView 6300P panel PCs are scalable to meet a range of performance requirements. They are available in display sizes from 12.1 to 24 in. and offer processing power based on the seventh-generation Core i3, i5 and i7 of the Intel Kaby Lake H platform. These units are available with analog resistive touchscreens, as well as projected capacitive touchscreens for applications utilizing multi-touch software. — *Rockwell Automation, Inc. Milwaukee, Wis.*
www.rockwellautomation.com

Powder sifters automatically remove foreign objects

GS centrifugal sifters (photo) automatically capture and remove foreign objects from granular and powdered product streams to prevent contamination and safeguard downstream equipment. Installed at the silo, bulk-bag discharge station or other storage unit, GS sifters pass the product stream through a rotating mesh screen sized to allow on-specification material to continue downstream while rocks, metal parts, bulk bag pieces and other foreign objects are blocked and diverted for analysis and disposal. Contaminants are safely removed, product quality assured, and downstream equipment protected from damage. The system's rotary sieves are offered in a choice of carbon steel, 304 stainless steel or 316 stainless steel with a dust-tight housing and a range of surface finishes to meet sanitary or hazardous-environment requirements. The sifters come with screens ranging in mesh sizes from 100 to 4,000 µm and a removable basket assembly for safe, complete screen cleaning. — *Gericke USA, Somerset, N.J.*
www.gerickegroup.com ■

Mary Page Bailey and Gerald Ondrey

Nickel-based Superalloys

Department Editor: Scott Jenkins

Superalloys, also known as high-performance alloys, are considered as materials of construction for process equipment in applications involving high temperatures, highly corrosive environments and those requiring high strength properties. Many commonly used superalloys in the chemical process industries (CPI) use nickel as their primary metal. This one-page reference provides information on Ni and reviews common Ni superalloys, including combinations of Ni with chromium, copper, iron, molybdenum, cobalt, titanium and other elements.

Nickel

Ni appears as a silvery-white metal, and is magnetic at ambient temperature. Its abundance in the earth's crust is 0.009%, a substantial amount of which arrived with meteorites. The world's nickel resources are currently estimated at almost 300 million tons, according to the Nickel Institute (Toronto, Ont.; www.nickelinstitute.org). Australia, Indonesia, South Africa, Russia and Canada account for more than 50% of global nickel resources. The minerals from which most nickel is extracted are iron/nickel sulfides such as pentlandite. It is also found in other minerals, including garnierite.

Under the unified numbering system (UNS) for metals, nickel and Ni-based alloys are designated with the prefix "N." Commercially pure (99.6%) wrought nickel (Nickel 200; UNS N02200) has good mechanical properties and corrosion resistance. Duranickel (UNS N03301) is the tradename for an alloy of nickel (94.0% Ni) with aluminum (4.5%) and titanium (0.5%) developed by Special Metals Corp. (New Hartford, N.Y.; www.specialmetals.com) that has greater strength and hardness than Ni 200.

Nickel retains an austenitic, face-centered-cubic crystal lattice structure up to its melting point (Table), so it avoids a ductile-to-brittle transition.

Ni-based alloys

Several properties of the element nickel have made it useful in the development of high-performance alloys. Chief among them is nickel's ability to alloy with most other metals. For example, complete solid solubility between nickel and copper, and wide solubility ranges between nickel and elements such as iron, chromium and others, exist, making many alloy combinations possible. The Ni content in Ni-based superalloys generally ranges from 53 to 99%. Once made, Ni-based alloys offer outstanding ductility, malleability and formability, and are easily weldable.

TABLE 1. PROPERTIES OF NICKEL (Ni)

Atomic number	28
Atomic weight	58.69 g/mol
Melting point	1,453ºC
Density	8.90 g/cm^3 at 25ºC
Coefficient of thermal expansion	13.4 µm / m K
Coefficient of thermal conductivity	90.9 W / m K
Young's modulus (measure of ability to withstand changes in length under tension and compression)	200 GPa
Bulk modulus (volumetric compressibility)	180 GPa
Curie temperature (magnetic behavior)	253ºC
Mohs hardness (scratch resistance)	4.0

Many nickel alloys perform well in temperatures up to 1,000°C, even for structural use. Ni-based superalloys exhibit excellent creep strength (resistance to deformation), oxidation resistance and fracture toughness. Commercial Ni-based alloys can be categorized generally into those made to withstand high temperatures and dry or gaseous corrosion, and a second group made for low-temperature (aqueous) applications.

Ni-Cu alloys

Nickel-copper alloys can have a range of mechanical properties, and are generally free from stress-corrosion cracking. They also exhibit good strength and toughness at sub-zero temperatures and are highly resistant to corrosion by saltwater.

Monel is a tradename for a series of Ni-Cu alloys made by Special Metals Corp. The most common of this series of alloys are Monel 400 (UNS N04400), Monel R-405 (a free-machining alloy), and Monel K-500 (improved strength and hardness compared to Monel 400).

Ni-Cr-Mo alloys

Nickel-chromium-molybdenum alloys provide high corrosion resistance, especially with reducing acids, such as hydrochloric acid (HCl) and sulfuric acid (H_2SO_4). Ni-Cr-Mo alloys are used for their ability to maintain high strength at high temperatures and corrosive environments.

Hastelloy is a tradename used by Haynes International (Kokomo, Ind.; www.haynesintl.com) for a series of Ni-Cr-Mo alloys. There are several grades of Hastelloy, and they are used in the construction of reactors, agitators, heat exchangers, reboilers, columns, trays, packing, pipework, couplings, valves, bolts, pumps, filters, dryers, and thermal oxidizers. These alloys provide improved performance over stainless steels at low and high temperatures.

An example composition of a common Ni-Cr-Mo alloy includes primarily Ni, with 15–17% Mo, 14.5–16.5% Cr, 4–7% Fe, 3–4.5% tungsten, and smaller concentrations of other elements, such as manganese.

Ni-Cr and Ni-Cr-Fe

Nickel-chromium alloys are noted for strength and corrosion resistance at high temperatures. Some of these alloys are derived from the Ni-Cr group by adding aluminum or titanium or both for precipitation hardening (a heat-treatment process that results in combinations of elements coming out of solution as small particles within the alloy's microstructure). Controlled precipitation hardening of Ni-Cr and Ni-Cr-Fe alloys allows increased strength and hardness. Several alloy variations in this class have been developed by Special Metals Corp. and are sold under the tradenames Inconel (a series that generally contains Ni and Cr with smaller amounts of Fe and other elements) and Incoloy (a Ni-, Cr- and Mo-containing series with Fe as the primary element). ■

Dimethyl Ether Production from Natural Gas and CO_2

By Intratec Solutions

Dimethyl ether (DME) is the simplest aliphatic ether, containing only two carbon atoms. This organic compound has been used in the production of the methylating agent dimethyl sulfate, and as an aerosol propellant, a coolant and in a number of other applications. Over the past few years, DME has been increasingly viewed as a "clean" and economical alternative fuel for diesel engines, able to achieve high performance and low emissions (CO, NOx and particulate matter) when burned as fuel.

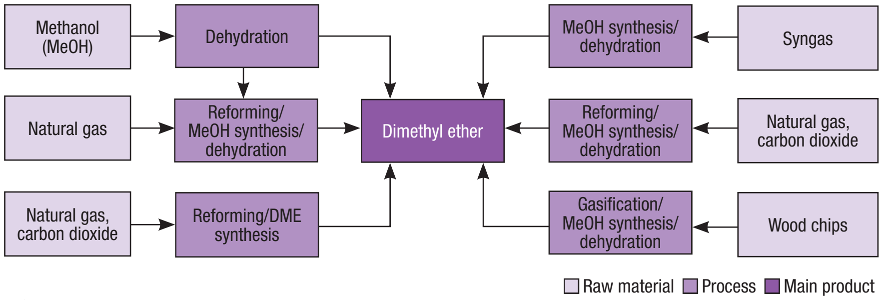


FIGURE 2. DME can be produced via a number of pathways, as shown here

The process

The present analysis discusses an industrial process for the production of DME from natural gas and carbon dioxide (direct method). The process comprises three major sections: (1) production of synthesis gas (syngas); (2) DME synthesis; and (3) purification (Figure 1).

Syngas production. Natural gas feedstock is treated in zinc oxide beds for removal of sulfur compounds, and in a pre-reformer (fixed-bed-type reactor) that converts higher hydrocarbons contained in the feed gas into a gas rich in methane and hydrogen, to protect the catalysts. Then, the treated gas is fed to a dry reformer, in which the methane reacts catalytically with CO_2, generating CO and H_2 (syngas). The reformer outlet stream is cooled, compressed and then fed to an absorption column for the separation of unconverted CO_2 using a methanol wash.

DME synthesis. The syngas is then fed to a fixed-bed synthesis reactor, in which it is directly converted to DME. Direct synthesis of DME in this way is carried out in the presence of a bifunctional zeolite-based catalyst system (Cu-Zn-Al/ZSM-5 catalyst). The reactor outlet gas mainly consists of DME, methanol, and unconverted hydrogen, CO and CO_2.

Purification. The effluent from DME synthesis is cooled, and DME and methanol are separated from the gases by condensation. The separated gas is partially recycled to the DME synthesis stage, with a small purge. The DME-methanol condensate stream is then passed through distillation columns. In the CO_2 column, carbon dioxide is removed from the DME and recycled to the dry reforming step. In the DME column, DME product is purified from methanol and directed to storage facilities located outside battery limits. Finally, wastewater is separated in the methanol column and the methanol obtained is recycled to the DME synthesis step.

Production pathways

Until the 1970s, DME was largely produced as a byproduct in the high-pressure production of methanol. Since this technology was phased out, different processes have been employed for DME production, including methanol dehydration, direct synthesis from syngas and others (Figure 2).

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce DME was about \$500 per ton of DME in the first quarter of 2017. The analysis was based on a plant constructed in the U.S. with capacity to produce 110,000 metric tons of DME annually.

This column is based on "Dimethyl Ether Production from Natural Gas and CO_2 (Direct Method) – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/dimethyl-ether-production-cost. ■

Edited by Scott Jenkins

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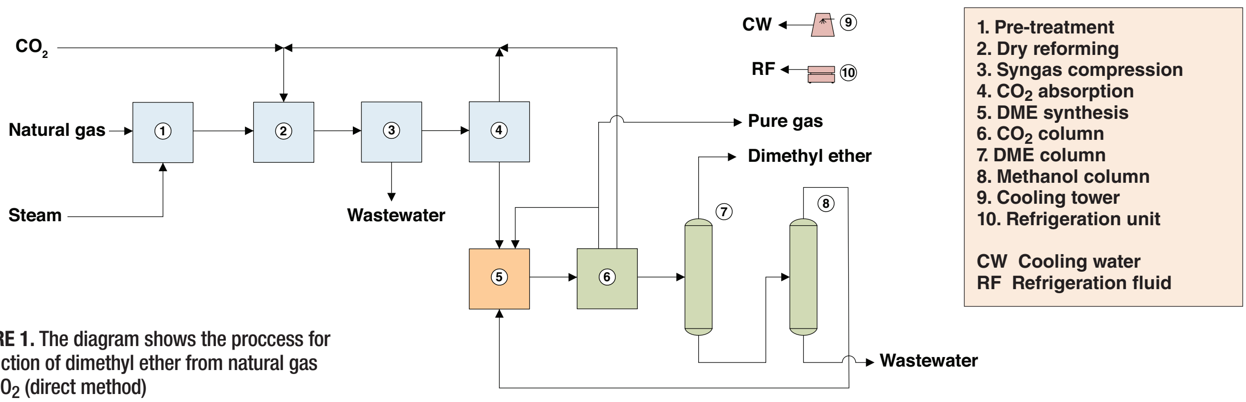

FIGURE 1. The diagram shows the proccess for production of dimethyl ether from natural gas and CO_2 (direct method)

Preventing Electrostatic Explosions and Fires

There are many occasions in chemical processing plants where electrostatic charge generation and accumulation can occur, potentially leading to fires and explosions. Engineers must understand these hazards and how to mitigate them

Vahid Ebadat
Stonehouse Process Safety

IN BRIEF

We are all familiar with the electrostatic shocks we receive at home or stores, perhaps from elevator buttons or shop displays, or when getting out of a car. These shocks are examples of "sparks" or sudden discharges of static electricity (Figure 1). They are a nuisance in a home setting, but in an industrial context, electrostatic discharges can and do cause many devastating flash fires and explosions. This is particularly true in the chemical process industries (CPI), where plants routinely handle flammable liquids and solids in ways that inadvertently generate static electricity. These materials are often flammable, of course, and they can be ignited by discharges of the static electricity that they have generated.

Whenever any two surfaces contact and then separate, static electric charge is generated. Most static charge is generated when fast movement and pressure are applied between the contacting surfaces. In the CPI, static electricity is generated in many common processing operations, such as when liquids flow through pipelines in a plant or when powder particles contact the surfaces of processing and conveying equipment. Therefore, some processes, such as fluidized-bed drying and pneumatic transfer, for example, will frequently generate a great deal of static charge, as will fast, turbulent liquid flow, such as in tanker unloading or filtration operations.

The main concern posed by static electricity in an industrial setting is the risk of fire and explosion due to the ignition of flammable atmospheres by electrostatic discharges. Flammable gases, vapors, dust clouds and aerosols are commonly encountered in processing operations, and precautions are required to prevent their inadvertent ignition. Precautions against fire and explosion are many and varied, but an approach that should be included is the exclusion or elimination of potential electrostatic ignition sources from locations where flammable atmospheres may reasonably be expected to exist.

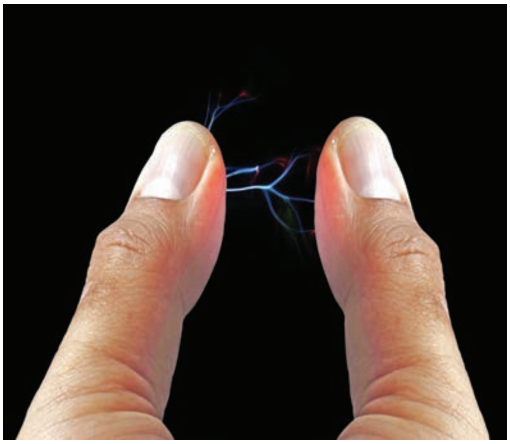

FIGURE 1. Electrostatic discharges are commonplace in many parts of life, but their presence in industrial settings can lead to destructive fires and explosions

There are many precautions that can be taken to control static electricity, but the best way to decide the most appropriate method for controlling static electricity in your plant is to first understand how static charge is generated and accumulated, as well as how it produces hazardous sparks that must be avoided.

This article discusses how, when and where electrostatic charge is generated in the CPI, why it accumulates to produce dangerous discharges and what practical measures can be taken to control the risk of explosions and flash fires due to static electricity.

The theory of charge generation

There are a number of different mechanisms that explain the generation of electrostatic charge. These include contact electrification, double-layer charging and induction charging.

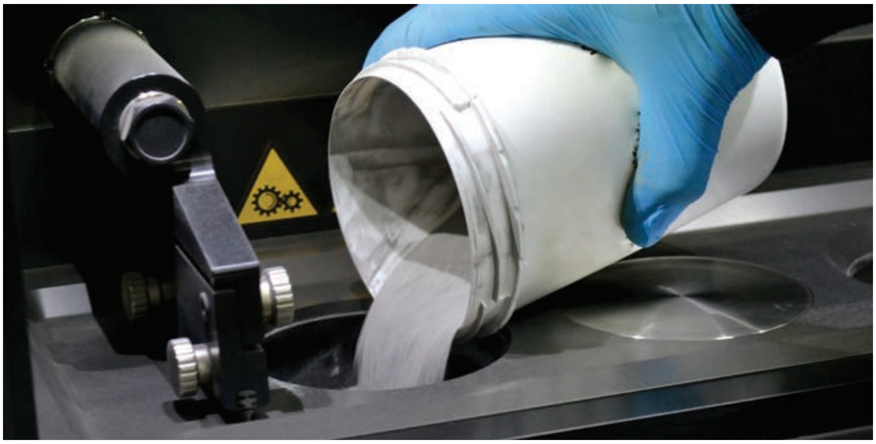

FIGURE 2. Powder particles and other bulk solids are a potential source of electrostatic shock in industrial settings

Contact electrification. A common way that materials become electrostatically charged in practice is through contact electrification — also known as triboelectrification. Contact charging occurs when any two materials come into contact and then separate. There is a rearrangement of electrons at the contacting surfaces where one surface is left with a surplus of electrons and is said to be negatively charged, while the other surface is left with a deficit of electrons and is said to be positively charged. Contact electrification occurs when, for example, powder particles collide or rub against the conveying chutes during pouring, and when the soles of footwear make contact with flooring. The level of charge that is generated by contact electrification is influenced by many factors, such as the chemical nature of the two contacting surfaces, the true contact area, contact pressure and surface conductivity. The handling and processing of bulk solids and powders typically result in the development of relatively high levels of static charge because many powders are electrically insulating (high resistivity), and powders have a relatively large surface area per unit mass available for contact electrification to take place (Figure 2).

Double-layer charging. Electrostatic charge is generated during the handling and processing of liquids by a mechanism known as double-layer charging. Double-layer charging can occur at liquid-solid and liquid-liquid interfaces. Ions of similar polarity are adsorbed at the interface. The adsorbed ions attract ions of opposite polarity in the liquid, forming a double layer near the interface with its containing structure. As the liquid flows relative to the interface, the oppositely charged ions shear apart, increasing the potential within the liquid. This effect, combined with the competing effect of ion recombination at the vessel wall, results in an unbalancing of charge within the liquid. This is the type of static charging that occurs, for example, when liquids flow through pipes. The factors that can aggravate charge generation in liquids include the following:

- Two-phase flow where a second liquid or solid phase is present in a continuous phase
- Strainers or filters in a line
- Processes that create excessive splashing and spray
- Movement due to mixing or stirring processes

It is important to note that the double-layer charging mechanism described here can take place even in a plant that is well grounded. Electrical grounding of a plant is important, but will not alone prevent charge generation.

Induction charging. Induction charging occurs when a conductive object that is electrically insulated from ground leaves (or enters) an electric field, such as that surrounding an adjacent charged object, for example. When in the field, the conductive object may slowly gain or lose charge at a rate determined by its capacitance and resistance to ground. If the conductor becomes sufficiently charged by induction, then there can be a risk of electrostatic discharge. It is generally possible to control such induction charging through the grounding of conductive objects.

Charge accumulation

The generation of electrostatic charge need not be hazardous. However, if static charge is allowed to build up on plant structures, people, or powder or liquid media, hazardous electrostatic discharges may result.

Plant, equipment and personnel. Where there is a charging process, charge can accumulate on the plant facilities, equipment or people if there is nowhere for it to escape — meaning that the plant structures, equipment or people are electrically isolated from ground (Figure 3). This charge buildup produces a voltage rise, which can introduce an ignition risk into hazardous areas where flammable atmospheres may be present. Additionally, the presence of insulating (non-conductive) plant structures or equipment in hazardous areas can lead to small electrostatic discharge from the surfaces of the insulators themselves. In some flammable atmospheres, these discharges can cause ignition.

Powders and liquids. Where there is a charging process, charge buildup is most likely to occur on powders or liquids that have high electrical resistivity (those that are poor conductors of electricity). In electrostatic terms, such highly resistive materials can hold charge for minutes, hours or longer — even if they are in contact with a plant structure that is electrically connected to ground.

Electrostatic discharges. Electrostatic discharges occur between two objects or surfaces that are at different electrostatic potentials (voltages). As an object or surface accumulates charge, the electric field strength above it intensifies. If the field strength between the objects or surfaces exceeds the breakdown strength of the atmosphere between them, an electrostatic discharge will occur. Such discharges have varying energy content, but may sometimes be sufficiently energetic to ignite nearby flammable atmospheres,

FIGURE 3. Both equipment and personnel are at risk to generate charge buildup that can introduce ignition risks

including the gases, vapors, dust clouds and aerosols typically found in CPI plants.

Effective discharge energy depends very much on the amount of charge accumulated and on the electrical properties of the surfaces or objects involved. Fortunately, engineers can gain insight about effective discharge energy by identifying the type and location of the discharge that could occur. Generally speaking, in most situations, the maximum energy of discharges from conductors can be significantly higher than those from people, which in turn can be greater than those from the surfaces of bulk powders and from plant structures and equipment made of insulating materials. There are overlaps and exceptions to this simple hierarchy of maximums, however, as the following sections explain.

So, the risk of igniting a flammable atmosphere with a discharge of static electricity depends both on the effective energy of the electrostatic discharge and on the sensitivity to ignition of the flammable atmosphere. The ignition sensitivity is a (measurable) property of the flammable atmosphere. The effective energies of electrostatic discharges found in a process environment are variable, but fall within ranges and are usually limited. We further develop these concepts in the following sections.

Flammable atmospheres

Perhaps the greatest hazard posed by an electrostatic discharge is as a potential ignition source for flammable atmospheres. The presence of three elements is required for a vapor fire or deflagration to occur: (1) a fuel; (2) an oxidant; and (3) a sufficiently energetic ignition source. For a dust explosion, two additional components are needed: (4) a dispersing mechanism (to make the dust airborne); and also (5) containment within the plant or the equipment. The main elements of a vapor fire or deflagration are commonly illustrated in a fire triangle (Figure 4) and as an explosion pentagon with dusts (Figure 5). Even in the presence of all three (or five) components, the fuel and oxidant mixture must be present between certain concentration limits to be flammable and capable of flash fire or explosion.

For an electrostatic discharge to ignite a flammable atmosphere, the effective discharge energy must be

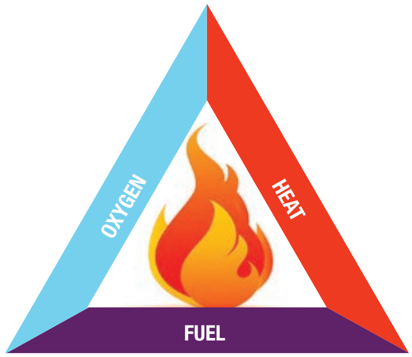

FIGURE 4. The three elements contributing to vapor fires or deflagration are heat, fuel and oxygen

greater than the minimum ignition energy (MIE) of the flammable atmosphere. The MIE is defined as the smallest electrostatic discharge energy that is capable of igniting the flammable atmosphere at its most easily ignitable concentration. The MIE of most hydrocarbon gases and organic vapors ranges from 0.1 to 1.0 millijoules (mJ), while the MIE of most dispersed dusts ranges from less than 3 mJ to over 1,000 mJ. While some literature data are available for MIEs of gases, vapors and dusts, it is generally recommended that such data be developed on a process-specific basis, since slight variations in composition or physical and chemical characteristics can have significant effects on MIE. For example, the MIEs of most powders and dusts decrease markedly as particle size or moisture content decrease. The MIE of a flammable atmosphere can be compared with the effective energy of any possible electrostatic discharges that could occur.

Control electrostatic hazards

The approach to the control of electrostatic hazards, as with other fire and explosion hazards that can occur in a CPI plant, involves measures to both prevent ignition and to protect plant and people from the consequences of a flash fire and explosion. The control of static electricity requires special focus, since it is not always apparent where charge can be generated and if the generation of charge is likely to cause a hazard or problem. A five-step approach is advocated for control of electrostatic hazards. These steps are as follows:

1. Collect flammability and electrostatic data on the possible flammable atmospheres that could be present
2. Collect data on the plant structures and equipment and process materials
3. Assess processes, plant facilities, equipment and people for charge generation and accumulation
4. Take measures to control static electricity
5. Implement change in the context of an approach to process safety that considers avoidance of flammable atmospheres, control of all ignition sources and measures to protect people and plant structures from the consequences of fire and explosion

Electrostatic characteristics

The first two steps in assessing electrostatic problems and hazards involve collecting information on flammable atmospheres (Step 1) and on the electrostatic properties of the materials processed, handled or used in the plant (Step 2), including the following:

- MIE of flammable atmospheres
- Resistance-to-ground of conductive (metal) objects and other plant items
- Electrical resistance of operators' body to ground (footwear and flooring)
- Electrostatic chargeability of powders and liquids (alternatively, measure surface voltage or electric field during processing)
- Volume resistivity of powders
- Conductivity of liquids
- Surface resistivity of solid objects, such as plastic containers and liners

National Fire Protection Association (NFPA) Standard 77, Recommended Practice on Static Electricity, provides valuable assistance in controlling the hazards associated with the generation, accumulation, and discharge of static electricity [*1*]. NFPA 77 provides a basic understanding of the nature of static electricity, provides guidelines for identifying and assessing the hazards of static electricity, as well as the techniques for controlling the hazards of static electricity.

Process, equipment and people

This section discusses some of the measures that can be considered to reduce the risk of flash fires and explosions due to electrostatic discharges from some common operations in the CPI, and how to assess processes for risk of charge generation (Step 3) and control static electricity (Step 4).

Conductive (metal) plant structures. The electrical resistance to ground of all conductive items in a plant, including metal pipes, equipment, vessels and containers, should be checked. If the resistance is greater than 10 ohms, direct ground connection will be required. It is important that the ground connections are checked regularly and that their purpose is known to the operators and maintenance personnel.

Personnel. Personnel wearing insulating footwear or working on insulating flooring (such as epoxy-coated or painted surfaces) can typically attain potentials of 10 to 15 kV by just doing various manual operations, such as walking around, putting on or taking off overalls, or pouring powders and liquids out of containers (Figure 6). Sparks from electrostatically charged personnel could have maximum discharge energies of up to about 30 mJ. The following measures should eliminate the possibility of electrostatic sparks from operators:

- Personnel should be grounded so that their resistance to ground is

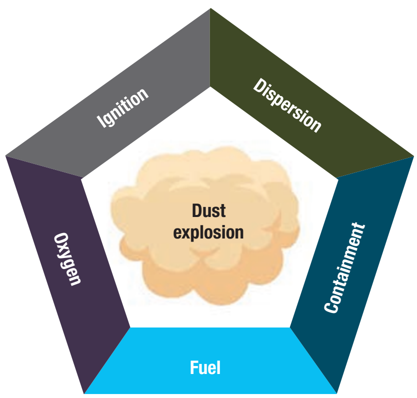

FIGURE 5. Dust explosions can occur when these physical components are present

FIGURE 6. Flooring and footwear can attain charge potential through everyday activities, and measures must be taken to decrease the possibility that sparks are formed

less than 1×10^8 ohm. This may be achieved by a conductive or static-dissipative flooring in combination with wearing static dissipative footwear with a resistance to ground between 5×10^4 and 1×10^8 ohm

- The resistance of the floor or surface on which the operator, wearing static-dissipative footwear, is standing should also be less than 1×10^8 ohm

Insulating (plastic) materials. Examples of insulating materials include plastic bags, liners, drums, pipes, hoses and plastic or glass-lined pipes and vessels. Non-conductive (insulating) materials typically have a surface resistivity greater than 1×10^{11} ohm/square. Non-conductive materials, such as plastic containers and liners, can become electrostatically charged by manual rubbing, causing brush discharges. Brush discharges can, in practice, only ignite flammable vapor or gas atmospheres with a MIE of less than about 4 mJ. More significantly, pneumatic conveying of powders through non-conductive (plastic) hoses and pipes can highly charge the inside surfaces of the hose or pipe, giving rise to propagating brush discharges. Similarly, highly charged liquids and powders entering non-conductive containers and liners can charge the inside surfaces of the container or liner and also result in propagating brush discharges. Propagating brush discharges can ignite all flammable vapor and gas atmospheres, and dust clouds with MIE up to about 2,000 mJ.

It is important to note that grounding of non-conductive materials would not facilitate the relaxation of electrostatic charges to ground. To avoid brush and propagating brush discharges, one must consider using conductive or static-dissipative materials with a surface resistivity less than 1×10^{11} ohm/square.

Liquids. Static-electricity hazards can arise in various liquid-handling operations, including filling, sampling, mixing and filtration. During liquid handing and processing operations, electrostatic charge can accumulate on the following: (1) bulk liquids in non-conductive containers and vessels; (2) low-conductivity liquids; and (3) liquid mists regardless of the liquid conductivity. The following suggestions can reduce the electrostatic ignition hazards:

- Make the plant electrically conductive and grounded — all items of the plant, including pipes, vessels, containers and so on should be electrically conductive or static dissipative and grounded
- Increase the liquid conductivity — an antistatic additive may be used in very small concentrations to raise the liquid conductivity
- Properly design and locate filters and valves — use valves with the maximum diameter possible. Locate filters and valves as far as possible

from the entrance to the receiving vessel

- Control the liquid entry to the vessel — liquid should enter a vessel through a drip leg with submerged ends or a bottom inlet point
- Control the flow velocity, using the following guidelines:
  - Liquids with conductivity greater than 100 pS/m: no flow velocity restrictions
  - Liquids with conductivity less than 100 pS/m and no immiscible components: flow velocity should be less than 7 m/s
  - Liquids with conductivity less than 100 pS/m and containing immiscible components: flow velocity should be less than 1 m/s

Powders. Highly charged powder particles entering a vessel can give rise to discharges on the surface of the bulk powder during filling of vessels. These are called bulk or cone discharges. The energy of these discharges depends on the powder's volume resistivity, electrostatic chargeability and particle size, as well as the vessel dimensions. Typically, these discharges bring a maximum energy of about 25 mJ.

Bulk discharges will not occur if the powder has a volume resistivity less than 10^9 ohm·m and if it is handled in a grounded, conductive plant. However, if the powder is insulating (meaning its volume resistivity is greater than 10^9 ohm·m), if its MIE is less than 25 mJ and if the electrostatic chargeability test results show that the quantity of electrostatic charge on the particles is sufficient to cause discharges from the surface of the bulk powder, then one of the following measures should be considered:

- Installation of inert-gas blanketing
- Installation of explosion protection and isolation measures
- Implementation of measures to reduce electrostatic charge generation and accumulation

Effect of humidity on charge accumulation. If water vapor is present in air, it absorbs onto surfaces and forms a slightly conducting surface layer. The extent to which the water absorbs and increases the conductivity depends on the nature of the surface and the humidity of the atmosphere. Although there is not a definitive relative humidity where the conductivity of all materials changes, holding the relative humidity at above about 65% at about 20°C may significantly reduce electrostatic effects.

Explosion prevention

The final step involves exploration and execution of explosion-prevention measures and avoidance of risk factors, such as flammable atmospheres and uncontrolled ignition sources.

Removal of flammable atmosphere. If the formation of a flammable atmosphere cannot be prevented or all ignition sources cannot be reasonably excluded or eliminated, then the risk of a fire or explosion will persist, and measures must be taken to protect against their consequences. One method of preventing a flammable atmosphere from forming is inert-gas blanketing or purging. This involves the introduction of an inert gas into a vessel or system to reduce the relative oxygen concentration to a level below which a fire or explosion cannot occur. This value is known as the limiting oxygen concentration (LOC).

Explosion protection. Explosion protection measures include containment, relief venting and suppression. Containment is achieved by designing vessels and equipment so that they are sufficiently robust to withstand and contain the maximum explosion pressure. Relief venting involves the installation of special panels on equipment that are designed to open at a pressure lower than the design pressure of the equipment. This protects the equipment from overpressure and relieves the explosion pressure and products to a safe area. Suppression is the rapid introduction of a suppressant to the incipient explosion. This prevents the course of the explosion from reaching a hazardous pressure and thereby protects the equipment from the explosion effects. These measures are often coupled with explosion isolation, which is the use of devices or methods to prevent the propagation or transfer of fires and explosions from one unit to another.

Final thoughts

Many industrial fires and explosions have been caused by discharges of static electricity igniting the flammable vapors and powders often found in CPI plants. Electrostatic charge generation most commonly occurs whenever materials — liquids or solids — come together and separate. In industrial processes, there are many occasions during the transfer, handling, processing and packaging of flammable liquids and powders where electrostatic charge generation and accumulation can occur, and sometimes electrostatic discharges will result. Fires and explosions occur when these discharges have more energy than the minimum required to ignite flammable vapors or dust clouds.

Whatever preventative and protective measures are considered (hardware or procedural), they must be effectively implemented, installed and maintained. Furthermore, staff need to be trained to understand electrostatic hazards and the measures in place to control static electricity. ■

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Moisture Measurement in Solid Materials

Determining moisture levels in solid materials is important for product quality, handling properties and other considerations. Provided here is an overview of direct and indirect methods for measuring moisture in solids

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IN BRIEF

Water is ubiquitous and is unusually reactive because of its high polarity. It not only bonds strongly to itself and to other polar molecules, but also bonds via physical forces to many other substances. These two factors — abundance and chemical reactivity — make the presence and detection of moisture of great concern to several sectors within the chemical process industries (CPI), such as food, paper and plastics. In these and other industries that produce powders and bulk solids, controlling moisture content can have a profound impact on product quality, as well as on the behavior of the solids in handling operations.

For example, moisture-related microbial growth is a key factor in pharmaceutical dosage forms, and can cause a number of quality issues, such as active pharmaceutical ingredient degradation and disintegration, discoloration or physical hardening of tablets. Similarly, moisture-related microbial growth is a key factor contributing to food spoilage if appropriate precautions for storage are not taken. Acceptable levels of moisture content vary from material to material, but in some cases, even trace amounts of water can adversely affect product quality.

In the context of solid material handling, moisture influences the intermolecular forces between solid particles in at least three ways: (1) it may adsorb onto the solid surface and influence the surface energy; (2) it may alter the surface conductivity and, consequently, the electrostatic charge of particles; and (3) it may condense in the capillary regions contiguous to the true areas of contact. In addition, moisture content provides information about texture, since increasing levels of moisture provides water mobility and lowers the glass-transition temperature.

Aside from product quality and material handling, moisture content can have an impact on shipping costs and product prices, all of which make it a highly consequential measurement. This article provides an overview of how water is taken up in solid materials and reviews both direct and indirect methods of determining moisture levels in solids. The most effective way to select a method is to carefully evaluate the needs of the operation. How the moisture measurement will be used should be a major factor in choosing a method.

Nature of water in solids

Water taken up by solid materials is generally classified as either water that is bound by physical forces or by chemical bonds. Physically bound water includes adsorbed water, trapped or liquid-inclusion water and absorbed water. Physical adsorption of water occurs when water condenses or is held on the surface, in the cracks and crevices of solid materials. Liquid inclusion occurs during the crystallization process, when bubbles of water are trapped. Water absorption is the process of taking up and retaining water uniformly throughout the structure of the host material. Examples of materials that can absorb large amounts of water are silica gel, cellulose, starch and agar.

Chemically bound water, or water of crystallization, is divided into two main categories: bound water and zeolite water. The two are distinguished by what happens to the crystal structure when the water is removed. If the crystal structure changes, it is bound water, but if the original skeletal structure remains, it is zeolite water. Bound water can be further subdivided into several categories, known as coordinated water, lattice water, hydronium-ion water, hydrogen-bonded water and decomposition water.

Mechanism of drying

Drying requires the removal of liquid from the solids. This liquid could be bound moisture or unbound moisture. Unbound moisture normally refers to water on the surface of a solid as a liquid film and is easily evaporated, while bound moisture may be liquid within

the solids or trapped in the microstructure of the solid. Bound moisture requires travel to the material's surface to be evaporated.

Moisture measurement techniques can be classified into direct and indirect methods. Direct methods for the determination of moisture in solids, with the exception of thermal methods, will not distinguish between bound and free moisture in organic materials. Thermal methods have traditionally been used to specify the kinds of moisture in materials. Indirect methods that show promise for distinguishing between bound and free moisture in organic materials are the dynamic dielectric thermal method and microwave infrared (IR), near infrared (NIR), reflectance and nuclear magnetic resonance (NMR) spectrometry.

During drying, two processes occur simultaneously:

1. *Heat transfer* is the transfer of heat from the surrounding environment to evaporate the surface moisture
2. *Mass transfer,* the transfer of internal moisture to the surface of the solid, and its eventual evaporation due to heat transfer, is a function of the physical nature of the solid, the temperature and its moisture content.

External drying conditions are important, especially during the initial stages of drying when unbound surface moisture is being removed. Surface evaporation is controlled by the diffusion through a thin film of air in contact with the solid's surface. The rate at which drying is accomplished is governed by the rate at which the two processes proceed. Energy transfer as heat from the surrounding environment to the wet solid can occur as a result of convection, conduction or radiation and sometimes as a combination of all these. In dielectric, radiofrequency or microwave drying, energy is supplied to generate heat internally within the solid and flows to the external surfaces.

H_2O activity & sorption isotherms

Knowing the moisture content of a product alone is insufficient to predict its stability. It is also necessary to know its water activity, a thermodynamic property describing the interactions between water molecules and the matrix (food, for example). Moisture sorption isotherms (the relationship between moisture content and water activity at constant pressure and temperature that describes the sorption process of water molecules into a specific material) are useful when identifying optimal food dehydration and storage conditions. Food manufacturers need to know how long it will be before their product develops mold, gets soggy, goes stale, becomes rancid, cakes, clumps, crystallizes and otherwise becomes unacceptable to the consumer.

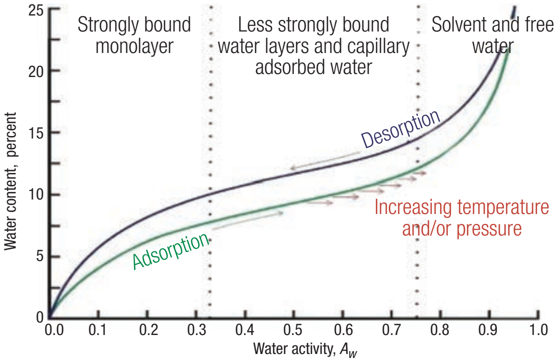

FIGURE 1. Ths graph is an example of a sorption isotherm for a typical food product

A moisture sorption isotherm is a powerful tool for predicting and extending the shelf life of a product. To create a moisture sorption isotherm, a dynamic vapor sorption (DVS) instrument is used. A sample is exposed to a stream of humidity-controlled air, while a microbalance measures tiny changes in weight as the product adsorbs or desorbs water. Once equilibrium is achieved, the instrument dynamically steps to the next preset humidity level. Tests take anywhere from two days to several weeks.

Water activity represents the energy status of the water in the system. It is equal to the relative humidity of the air in equilibrium with a sample in a sealed chamber. It is defined as the vapor pressure of water in a sample divided by the vapor pressure of pure water at the sample temperature.

Water activity is measured using either a capacitance instrument or a chilled-mirror water activity instrument, while moisture content is measured using any one of the 35 different methods listed in the current official methods of AOAC International (Rockville, Md.; www.aoac.org). Water activity and moisture content together provide a complete moisture analysis.

The typical shape of an isotherm reflects the way in which the water binds the system. Weaker water molecule interactions generate a greater water activity. Thus, the product becomes more unstable. Water activity depends on the composition, temperature and physical state of the compounds [*1*]. Sorption isotherms can be generated from an adsorption process or a desorption process, and the difference between these curves is defined as hysteresis (Figure 1).

An isotherm can be typically divided into three regions. The first is strongly bound water, where the enthalpy of vaporization is considerably higher than that of pure water. The bound water includes structural water (H-bonded water) and monolayer water, which is adsorbed by the hydrophilic and polar groups (such as polysaccharides, proteins and so on) of solid products. Bound water is unfreezable and it is not available for chemical reactions or as a plasticizer.

In the second region (less strongly bound), water molecules bind less firmly than in the first zone, and are usually present in small capillaries.

The properties of water in the third region are similar to those of free water that is held in voids, large capillaries and crevices in the solid product. The water in this region loosely binds to solid materials, such as food products [*2–5*].

Moisture sorption isotherms are extremely important in several areas: modeling the drying process; designing and optimizing drying equipment; predicting shelf-life stability; calculating moisture changes that may occur during storage; and selecting an appropriate packaging material. Understanding of principles and application of moisture sorption isotherms is essential for knowing product-water interactions. Moisture content by water activity is an excellent option for measurement of moisture content, and is especially attractive when both water content and water activity measurements

TABLE 1. MOISTURE MEASUREMENT METHODS [12]			
DIRECT		INDIRECT	
Gravimetric		**Optical**	Infrared Infrared thermography Hyperspectral imaging
Chemical	Karl Fischer Coulometric	**Dielectric**	Electrical conductivity Microwaves Radio frequency (RF)
		Nuclear	Proton nuclear magnetic resonance (NMR)
		Hygrometric	Equilibrium relative humidity

are needed for the same sample. A product-specific isotherm is needed, which can be obtained manually or using an isotherm generator. The precision of this method is the best of any of the secondary methods and exceeds that for loss on drying.

Moisture measurement in solids

The conclusion of a drying process can best be confirmed by measuring residual moisture in the subject product. There are several techniques common within the various CPI sectors to measure the moisture content of solids at the end of the drying step. Moisture-measurement methods can be generally classified as direct or indirect. In the direct methods, moisture is normally removed from the solid material by drying, distillation and other means, and its quantity is found by weighing, titration and so on. On the other hand, for indirect methods, moisture is not removed from the material, but instead, measurements are made of the properties of the wet solid that depend on the amount of water present or the number of hydrogen atoms. Indirect methods must be calibrated with standards that have been prepared by using one of the direct methods. Direct methods generally require manual sampling, several minutes to express a result, and are highly subject to operator error.

The integrity of the material sometimes changes along with loss of moisture as the product is drying. For example, a product might see a chemical change due to decomposition, or oxidation, among other physical changes. There are various techniques to determine the moisture, but a number of factors must be taken into account. These factors include the desired accuracy, the procedure, the sample size and the location of the sample or the probe within a dryer. All have the potential to produce different results.

Direct methods

The following describe direct measurements for moisture in solids.

Vacuum oven or vacuum desiccator. Determination of moisture content of a sample is accomplished by drying in a vacuum chamber. A sample of about 4–5 g is placed in a

dry, preweighed glass container and placed in the drying chamber and dried at 102–105°C. The measurement of the dried sample is carried out at ambient temperature after the sample is cooled. Although simple in concept, there are implicit assumptions and many pitfalls to this approach. First among these is the assumption that water is the only volatile species that will evaporate under the specified drying conditions. Secondly, the conditions of drying (time, temperature, pressure and type of atmosphere) must be carefully specified.

TABLE 2. LIST OF MOISTURE MEASUREMENT SUPPLIERS [*12*]

Method	Measurement Technique	Company
Gravimetric	Thermogravimetric analysis	CSC Scientific Co.; Tovatech LLC; Gardco; PCE Instruments; Tester Co. (U.K.); AMETEK Brookfield; Mettler Toledo
Chemical	• Karl Fischer titration • Coulometric	Clarkson Laboratory and Supply Inc.; CEM
Optical	• Infrared spectroscopy • Infrared thermography	MoistTech Corp.; PCE Instruments; Kett U.S.
Dielectric	• Electrical conductivity • Microwave • Radio frequency	PCE Instruments; Berthold Technologies; CEM
Nuclear	• Nuclear magnetic resonance (NMR) • Neutron and gamma-ray scattering	Berthold Technologies Oxford Instruments
Hygrometric	Equilibrium relative humidity	Meter Group Inc.

Electrical methods. Another system for moisture detection is based on the fact that many materials change electrical or dielectric characteristics depending on the moisture level in the material. Most of these instruments measure changes in resistance, conductivity or capacitance. Because these techniques are measuring an indirect effect of moisture, calibration is necessary. The calibration is accomplished by comparing the dielectric reading to a known moisture for the sample. A graph is prepared and used to provide the translation of the electrical characteristic to the amount of moisture in the material sample. In automated instruments, these tables are processed by a computer to give readings in percent moisture.

Chemical method. Karl Fischer titration (KFT) is a widely used analytical method for quantifying water content in a variety of products. The fundamental principle behind it is based on the Bunsen reaction between iodine and sulfur dioxide in an aqueous medium. Coulometric Karl Fischer titration is the most widely used technology to determine residual water content. Some chemicals are known to cause problems with Karl Fischer titration, but these chemicals do not usually occur in biologics.

As shown in Equation (1), the Karl Fischer method uses Karl Fischer reagent, which reacts quantitatively and selectively with water, to measure moisture content. Karl Fischer reagent consists of iodine, sulfur dioxide, a base and a solvent, such as alcohol.

$$I_2 + SO_2 + 3Base + ROH + H_2O \longrightarrow 2Base + HI + Base + HSO_4R \qquad \mathbf{(1)}$$

The alcohol (ROH) reacts with sulfur dioxide (SO_2) and base to form an intermediate alkyl sulfite salt, which is then oxidized by iodine to an alkyl sulfate salt. This oxidation reaction consumes water. Water and iodine are consumed in a 1:1 ratio in the reaction. Once all of the water present is consumed, the presence of excess iodine is detected voltametrically by the titrator's indicator electrode. In other words, information about an analyte is obtained by measuring the current as the potential is varied. That signals the endpoint of the titration. The amount of water present in the sample is calculated based on the concentration of iodine in the Karl Fisher titrating reagent (titer) and the amount of Karl Fisher reagent consumed in the titration.

There are two types of Karl Fischer reactions: volumetric KFT and coulometric KFT. In volumetric KFT, iodine is added mechanically to a solvent containing the sample via the burette during the titration. Water is quantified on the basis of the volume of Karl Fischer reagent consumed. Volumetry is best suited for the determination of water content in the range of 100 parts per million (ppm) to 100%. In coulometric KFT, iodine is generated electrochemically in situ during the titration. Water is quantified on the basis of the total charge passed (Q), as measured by current (amperes) and time (seconds), according to the relationship in Equation (2).

$$Q = 1\text{ C (Coulomb)} = 1\text{ A} \times 1\text{ s}$$
$$\text{where } 1\text{ mg } H_2O = 10.72\text{ C} \qquad \mathbf{(2)}$$

Coulometry is best suited for the determination of water content in the range of 1 ppm to 5%.

Capacitive method. This is the least expensive and easiest-to-handle moisture-measurement method, and it provides accurate, repeatable results for a variety of materials at high frequencies. The capacitive (also called high-frequency dielectric shift) sensor measures moisture based on the difference between the dielectric constants of water and the material located between the sensor's capacitor electrodes. Most solids have a dielectric constant between about 4 and 13. Water has a dielectric constant of about 80. The sensor measures this difference to determine the material's percentage of moisture content by weight. When the capacitive sensor measures an increase in the material's capacitance toward that of water's dielectric constant, the increase indicates the material contains more moisture. The capaci-

Mettler Toledo

FIGURE 2. An example of a thermogravimetric moisture analyzer is shown here

AMETEK Brookfield

FIGURE 3. This thermogravimetric device is ideal in applications where Karl Fischer titration is used

tive sensor provides realtime measurement and can be used as either a contact or noncontact method.

Thermogravimetric (loss on drying) method. A loss-on-drying (LOD) instrument for bulk-solid moisture analysis uses the same theory as standard oven methods: An empty sample pan is weighed and tared. A sample is added and recorded as the initial starting weight. Heat is applied to the sample to evolve moisture (or other volatile compounds). The difference in sample weight is recorded and calculated as percent moisture using the following relationship: Initial weight of the sample – Final weight of the sample = Loss in weight; Loss in weight × 100 = % moisture.

With a LOD instrument, the balance and heat source are coupled together, allowing the user to view realtime moisture curves and rate graphs as moisture is evolved. In the integrated system, test times are substantially faster with the same level of accuracy one would expect from traditional oven methods. The use of thermogravimetric analysis, with evolved gas mass spectrometric monitoring, was a successful alternative for moisture analysis in lyophilized materials [*6*]. The authors reported that the thermogravimetric analysis (TGA) method was capable of analyzing these samples without any fundamental difficulties, other than the need to pack sufficient material into the TGA sample pan. By contrast, these lyophilized samples could not be successfully analyzed by the coulometric Karl Fischer method without costly repeated changing of the reagents and cleaning of the cell every 2–3 samples.

Moisture analyzer HE53, made by Mettler Toledo (Figure 2) is a very common instrument using a thermogravimetric principle. Vapor Pro XL, made by AMETEK Brookfield (Figure 3) is also a thermogravimetric base unit ideal for nearly any application in which Karl Fischer titration is used. The SMART 6, from CEM (Figure 4), is a microwave moisture analyzer for rapid moisture measurement.

Indirect methods

For moisture determination instruments in general, applying the concepts of reflection and absorption of electromagnetic energy is becoming widespread, particularly for in-line or on-line measurements. These techniques are based on the finding that water (as well as other chemicals) has very specific absorption wavelengths. Instruments based on the absorption of near infrared (NIR) and microwave radiation technology are the most common. Although the two techniques are different, both are based on the absorption of electromagnetic

CEM

FIGURE 4. Shown here is an example of a microwave-based moisture analyzer device

energy. When the moisture content of a calibration sample is known, the absorption results can be referenced to the moisture content of the sample. The use of lasers for this purpose is a newer, but related, technique.

Near infrared (NIR). Infrared sensors measure the moisture content by passing a light beam at infrared wavelengths through the material and measuring the ratio between absorbed and reflected wavelengths. NIR spectroscopy is a well-established technology for online moisture testing. NIR reflectance spectrometry utilizes the near-infrared diffuse reflectance radiation from a solid sample at several discrete wavelengths to predict moisture and other chemical species in the material. A light source is collimated and filtered into specific wavelengths. Water displays the characteristic absorption at a near-infrared range between 1,100 and 2,450 nm. The filters are chosen such that one wavelength will be absorbed by water (sample beam) and one wavelength will be unaffected by water (reference beam). In consequence, the amplitude ratio of the two reflected wavelengths will be proportional to the amount of water in the product. This filtered beam is directed onto the surface of the sample to be measured. One part of the light is reflected back to a detector. Chemometric methods then also allow the calculation of water contents in different matrices. NIR can be universally applicable with any molecule containing C-H, N-H, S-H, or O-H bonds. It does not require sample preparation and is very fast.

Handheld portable NIR units (Figure 5) are offered by the industry that allows even less-trained personnel to take portable, instant moisture readings of powdered bulk products as needed. The approach involves moisture meters that utilize NIR light, a highly accurate, non-contact secondary measurement method that can deliver immediate, laboratory-quality moisture readings. In addition, because the process is non-destructive, samples remain unaltered so they can be used for additional tests or put back into the product stream. NIR is limited in the fact that it only measures surface moisture and does not penetrate the interior of the material.

Microwave moisture measurement. Microwaves are a part of the electromagnetic spectrum, with wavelengths in the centimeter range, bounded by the longer radio waves and the shorter infrared waves. The frequencies of microwaves range roughly between 10 and 10,000 MHz. The microwave oven is a device in which dielectric heating is affected by high-frequency electromagnetic waves. This type of heat forms as a result of dielectric losses that occur in a material that is located between the metal walls of the oven, which act as a capacitor connected to a high-frequency generator, the magnetron. The effectiveness of dielectric heating in a microwave oven is strongly dependent on the polarity of the material exposed to the electromagnetic field. Polar molecules (dipoles), in which the centers of positive and negative charge do not coincide, are in thermal equilibrium in the absence of an electromagnetic field. When an electromagnetic field is applied, the dipoles orient themselves quickly and repeatedly in the direction of the field. The continual molecular motion generated by the alternations of the field causes the material to heat by intermolecular friction. This type of heating is rapid because, unlike conventional heating, the heat does not need to be conducted through the material starting from the surface but is generated rather uniformly inside the material.

Microwave sensors measure the loss of energy of microwaves passed through the sample at the point of emission, and use the difference in their speeds in different media to calculate the moisture content. This loss in energy increases with the amount of water that the medium contains, with the result that, as the water concentration increases, less energy will reach the other side of the medium. Microwave sensors are very accurate in measuring moisture in very fine uniformly distributed materials. Microwave techniques are attractive because at these frequencies (below the 2.5 GHz range} the electrical energy is strongly absorbed by water because of the dipolar character of water molecules, and the effect of ionic conductivity is negligible. Moisture content has been related to dielectric properties. The advantage of using this technique over the traditional oven-dried methods is that permittivity can be measured in near realtime. Because of its high susceptibility to water, microwave technology has established a strong foothold for moisture analysis of food and agricultural products.

In the pharmaceutical industry, the response to the process analytical technology (PAT) initiative of the U.S. Food and Drug Administration has been a rising interest in the development of microwave sensors for the remote, on-line moisture sensing of pharmaceutical intermediates and products during processing. Compared to NIR waves, which are sensitive primarily to surface moisture, the lower frequencies and thus higher penetration depths of microwaves are more advantageous because they allow the detection and quantification of moisture entrapped or embedded within a product [*7*]. In two recent studies, microwave sensors were used for in-situ moisture determination of wetted powders and granules during high shear granulation [*8*] and fluidized-bed drying [*7*], respectively.

FIGURE 5. Handheld near infrared (NIR) moisture analyzers allow personnel to take moisture readings with a portable instrument

FIGURE 6. Microwave moisture sensors, like the one shown here, can be valuable in many different proces stages

The use of a microwave moisture meter, as opposed to a humidity sensor, provides a very consistent and high product quality while reducing operating and maintenance costs. When connected to a controller or a process control system, the operator has the opportunity to interact with the measurement results in real time. For online moisture measurement in production processes, the microwave sensor (Figure 6) is valuable in many process stages: in the refining of wood pulp, during resin treatment, during pressing/dewatering, and during the final drying. When used for measuring the moisture content of sawdust or larger wood chips, the microwave sensor provides exceptionally accurate measured values if the wood pulp is homogeneous, well mixed, and pre-dried to avoid "moisture nests" in the wood pulp mixture.

Nearly all bulk goods can be measured by microwaves. There are very few materials with restrictions. Problems can, however, arise in the rare case where the water molecules are not able to rotate, for example, if they are captured in capillaries. For the same reason, crystal water and ice do not respond to the measurement. To address fluctuation in the drying of grain continuously researchers have used online measurement using the microwave resonator technique [*9*].

Nuclear magnetic resonance (NMR). The low-resolution broad-banded NMR spectrum of water and ice shows that the tightly bound protons in the solid and the mobile water protons in the liquid can be separately quantified. This approach can also be used to determine the amounts of free and bound moisture in solid substances. [*10, 11*]. In a 2002 paper [*12*], researchers at the Lawrence Berkeley National Laboratory (www.lbl.gov) developed a device that measures the water content of woodchips, pulp and brown stock for the paper industry. This device employs a permanent magnet as the central part of an NMR measurement system. The report describes the magnet and the NMR measurement system. The results of water content measurements in woodchips in a magnetic field of 0.47 T are presented. They also found, as was reported in an earlier study, that the NMR moisture content measurements can differentiate between pore moisture and surface moisture. Moisture in the form of liquid water can be differentiated from water in the form of ice. Being able to differentiate water from ice means that NMR can be used in a number of areas in the forest products industry.

Optical method. Because the water molecule has distinct optical properties, moisture detection using optical techniques allows a new method of on-line measurement. This approach is non-intrusive to the product, capable of realtime measurement and can be automatic. The optical absorption of water occurs at distinct wavelengths, with very high absorption in the IR range and a slightly reduced absorption in the NIR. Depending on the moisture range of interest and the substance in which it is being measured, each wavelength region can be utilized with the same net benefits. Typical IR measurement are better for moisture levels less than ~1%, while NIR measurement is better for moisture greater than ~1%. Sampling options range from flow cells with selectable path lengths, to measuring heads that mate to sight glasses in vessels, to fiber probes for contact or non-contact measurement in various insertion points. The dynamic-equilibrium moisture content of rice by the optical method was measured and was consistent with the actual drying method. The experimental results were compared with the results of other measurement methods for correction, in order to achieve real-time measurement and analysis of the batch re-circulating rice drying process [*14*]. ■

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Practicing Year-Round Waste Compliance

There are many regulations surrounding the production of waste at manufacturing facilities. By approaching regulatory practices in a proactive manner, sites can ensure personnel and environmental safety, as well as continuous compliance

Wade Scheel
Clean Earth

When it comes to handling hazardous waste in the chemical process industries (CPI), it can be challenging to keep up with the ever-changing federal and state regulations. For those responsible for the cleaning and upkeep of facilities, it is crucial to stay up to date on industry changes to ensure compliance and avoid potential fines and penalties.

A quick search for "hazardous waste fines" brings a long list of businesses in every industry being penalized for mishandling disposal of hazardous waste. Because waste-handling is a highly regulated sector where regulations change all the time, manufacturers cannot afford to leave compliance to chance. In fact, one large manufacturing company was recently fined hundreds of millions of dollars for noncompliance due to decades-long contamination of groundwater.

We continue to see companies of all sizes receive hefty fines for hazardous-waste disposal violations. From a regulatory perspective, the U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) can fine up to $75,867 per day per violation, especially for repeat offenders. As an example, if a manufacturer has a container storing hazardous waste without a lid properly secured on it, the EPA has the authority to determine how long the violation has occurred and can then fine the plant for every day of the non-compliance. Fines can also vary state by state.

Hazardous waste must be managed and disposed of properly, and inadequate waste management presents potential health and safety risks to people within a facility, in the surrounding community and in the wider environment. That is why it is important keep abreast of regulatory changes and updates year-round to make sure a manufacturing facility is meeting all compliance requirements.

Laboratories, healthcare practices, manufacturing plants and other facilities accrue hazardous chemical waste in both work and storage areas. In fact, it is reported that approximately 7.6 billion tons of industrial solid waste are generated and disposed of each year in the U.S. [*1*]. This means that there is no shortage of regulated items accumulated throughout the year that need to be managed and disposed of in a safe and compliant way. Whether a professional works for a large chemical plant or a small manufacturing business, it is important to take the necessary planning steps to ensure hazardous waste is properly managed.

FIGURE 1. Compliance with federal regulations involves properly assessing, categorizing, segregating, storing, transporting and disposing of all hazardous waste

TABLE 1. EPA'S LISTED HAZARDOUS-WASTE DEFINITIONS [*2*]

U	Hazardous wastes from discarded or unused commercial chemical products; specific wastes are listed in EPA's 40 CFR section 261.33
P	Acute hazardous wastes (typically toxic in smaller quantities) from discarded or unused commercial chemical products; specific wastes are listed in EPA's 40 CFR section 261.33
F	Wastes from non-specific sources, including: spent solvents; electroplating and other metal finishing wastes; dioxin-bearing wastes; chlorinated aliphatic hydrocarbons production; wood-preserving wastes; petroleum-refinery wastewater-treatment sludges; and multisource leachate
K	Source-specific wastes from the following industries: wood preservation; organic chemicals manufacturing; pesticides manufacturing; petroleum refining; veterinary pharmaceuticals manufacturing; inorganic pigment manufacturing; inorganic chemicals manufacturing; explosives manufacturing; iron and steel production; primary aluminum production; secondary lead processing; ink formulation; and coking

With the U.S. government's increasing focus on enforcing regulations, not assessing, categorizing, segregating, transporting and disposing of all waste types in a compliant manner can result in fines and violations that are detrimental to manufacturers in every industry (Figure 1). Following the tips outlined in this article will help any manufacturing facility to practice year-round waste compliance.

Identify hazardous waste

Before anything else, it is best to first understand what is defined as hazardous waste. The EPA defines hazardous waste as "waste with properties that make it dangerous or capable of having a harmful effect on human health or the environment." Once an item containing hazardous properties is no longer usable for its intended purpose, it is deemed hazardous waste.

To be considered hazardous waste, the item must exhibit ignitable, corrosive, reactive or toxic characteristics. The item may also be on the EPA's U, P, F or K lists of hazardous wastes (Table 1). While the immediate assumption for some manufacturers might be that they only have non-hazardous chemi-

cal waste, there are several different types of hazardous waste to be aware of when sorting and managing materials.

Once facility operators have an understanding of hazardous waste, the next step is to educate all appropriate employees on current and future regulations that could impact the facility (Figure 2). The following sections describe some of the most common and recent regulations.

Resource Conservation & Recovery Act (RCRA). The EPA regulates hazardous waste under RCRA, which was enacted in 1976 to ensure these wastes are managed in a compliant manner. The act mandates that generators of hazardous waste are responsible for waste from the time of generation to the final destruction, and sees that these wastes are managed in ways that protect human health and the environment. Generators of hazardous waste are regulated based on the amount of hazardous waste they generate in a calendar month, not the size of their business or facility. At the federal level, there are three generator categories: very small quantity generator (VSQG), small quantity generator (SQG) and large quantity generator (LQG) [*3*].

e-Manifest. The Hazardous Waste Electronic Manifest Establishment Act (e-Manifest) was enacted in 2012 with a goal of creating a national system for tracking hazardous waste shipments electronically, resulting in a centralized database that could be accessed in real time by the regulated community. The EPA's intent to update the system was to improve access to higher quality and timelier hazardous-waste shipment data and to save industries and states valuable time and resources. The EPA estimates that e-Manifest will ultimately reduce the burden associated with paper manifests by between 170,000 and 425,000 hours, saving state and industry leaders more than $50 million annually, once electronic manifests are widely adopted [*4*].

FIGURE 2. All pertinent personnel must be apprised of which regulations impact their facility, and the steps they can take to achieve compliant status

In October 2019, submission fees increased significantly, with the following fees effective through September 2023:

- $8 per manifest (previously $5) for electronic manifest, both fully electric and hybrid
- $14 per manifest (previously $6.50) for data and image upload
- $20 per manifest (previously $10) for scanned image upload
- $25 per manifest (previously $15) for mailed-in paper manifest

Hazardous Waste Generator Improvements Rule. Signed in October 2016, this final rule was intended to provide more clarity and flexibility to businesses. The rule enhances the safety of facilities, employees and the general public by improving communication surrounding hazardous waste risks and ensuring that emergency management requirements meet today's needs. The rule includes more than 60 changes to the Hazardous Waste Generator program first introduced in 1980 under RCRA, and the rule aims to close important gaps in the regulations. Adoption of the rule varies state by state [*3*].

Some states are authorized to establish generator categories that differ from those established by the federal government. To help current and potential hazardous waste generators follow state regulations, the EPA lists the states that have regulations differing from federal regulations and which states have the same generator categories. EPA also lists links to rules or guidance for those states that have different regulations [*3*].

Practice compliance year-round

It is highly encouraged to make sure a facility is staying compliant year-round. Similar to the unadvisable nature of beginning a large project within a few days of deadline, it is best to make sure that personnel at a facility handling waste are taking the necessary steps all year long. While it can be overwhelming to ad-

FIGURE 3. Labeling is a crucial aspect in ensuring compliance with hazardous-waste regulations

here to state and federal regulations, the following best practices can help sites to remain penalty-free.

Segregate incompatible chemicals. Incompatible hazardous wastes must remain separate, so it is recommended to use separate accumulation bins or drums that are designated for each specific categories of waste, such as aerosols, flammables, toxics, corrosive acidic, corrosive alkaline (basic), oxidizers and universal waste.

Label containers. Once the hazardous waste is placed into a drum or tank, the container must be properly labeled as required by regulations. Containers should be marked as "hazardous waste," "non-hazardous waste" or "universal waste," and include the accumulation start date, as well as an indication of the hazardous characteristic of the contents (Figure 3). It is also best management practice to include the contents on the label. If an inspector from the city, state or federal regulatory body visits the facility, proper labeling is one of the first things that they will examine. States often have specific hazardous-waste labeling requirements and may require regular inspections of hazardous waste accumulation containers and storage areas.

Ensure proper storage. All hazardous waste should be stored in a dedicated, permanent, clean and organized hazardous-waste area. The ideal location is away from highly trafficked areas, electrical panels, perishable or consumable product storage and dock doors. The containers should be placed on an impervious surface, such as pavement or tile, without floor drains.

Keep proper records. Maintaining an inventory log will help professionals manage and track waste generation volumes. Every time an item is identified as hazardous waste and placed into an accumulation container, it should be noted on the log and kept in the facility's records. Without proper record-keeping and thorough paperwork, manufacturers run the risk of being fined.

Once items are segregated and stored properly, hazardous waste disposal should be done in accordance with state and local regulations.

The severity of non-compliance

There are many consequences of improperly handling hazardous waste at any given time. Facility operators that do not understand federal, state and local regulations face environmental, health and safety risks, as well as chemical destruction. In addition, facilities may incur significant monetary penalties. While the financial burden of non-compliance is substantial, the negative impact these public fines have on brand perception can be even more damaging.

As environmental issues are a growing concern for the public, local and even national news outlets are quick to pick up on any perceived offenses made by corporations. Additionally, the proliferation of social media means that negative news about environmental fines or improper disposal of hazardous waste spreads quickly and widely across those channels. Common missteps that could result in fines include the following:

- Lack of, or improper, labeling
- Open containers of hazardous waste onsite
- Dumping hazardous waste down the drain
- Not possessing (or possessing inadequate) hazardous-waste manifests
- Failing to properly train employees in hazardous-waste management, handling and emergency preparedness
- Lacking compliance with hazardous-waste generator regulations
- Not having hazardous-waste determinations on file

If a facility decides to not participate in routine hazardous-waste pickups throughout the year, it should understand the importance of staying compliant without the help of a third-party service provider. The average cost of having a proactive environmental-compliance program for hazardous-waste varies, but with millions of dollars in potential fines at stake for non-compliant practices and consumer loyalty at stake, organizations must be well informed about changes from regulators and update their hazardous-waste management programs accordingly.

Utilize a partner

With regulations varying state by state, as well as at a federal level, it can be extremely helpful to have a highly trained expert visit a site to identify best practices for managing the waste being generated. These teams of engineers, chemists and environmental health professionals understand that managing waste on an industrial scale often has two practical objectives — minimizing long-term liability and controlling costs — and can work to help a company achieve those goals. Ultimately, manufacturers should strive to minimize or completely remove the generation of hazardous waste by eliminating as many of its waste streams as possible throughout the year. By managing hazardous waste in a safe and compliant way by following regulations and partnering with an experienced waste services provider, facilities are able to ensure the protection of the public, employees, the environment and their overall brand. ■

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Economic Indicators

2018 2019 2020

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Oct. '20 Prelim.	Sept. '20 Final	Oct. '19 Final
CE Index	595.9	593.7	599.3
Equipment	720.7	717.2	727.6
Heat exchangers & tanks	607.6	605.8	627.7
Process machinery	720.9	717.9	721.7
Pipe, valves & fittings	965.1	954.0	958.4
Process instruments	421.0	422.1	420.5
Pumps & compressors	1084.0	1084.0	1072.3
Electrical equipment	568.9	565.0	560.8
Structural supports & misc.	755.1	752.7	771.7
Construction labor	337.7	337.6	337.6
Buildings	616.7	616.1	589.3
Engineering & supervision	310.9	311.8	313.8

Annual Index:

2012 = 584.6

2013 = 567.3

2014 = 576.1

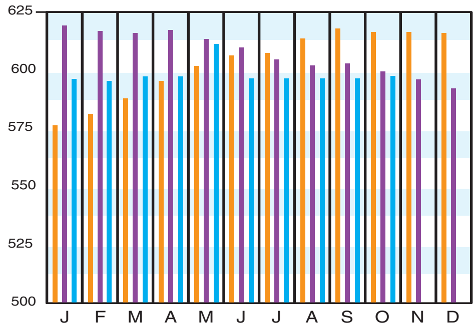
2015 = 556.8

2016 = 541.7

2017 = 567.5

2018 = 603.1

2019 = 607.5

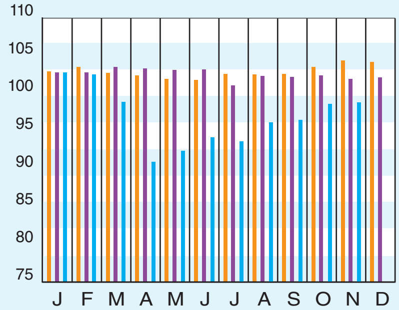


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

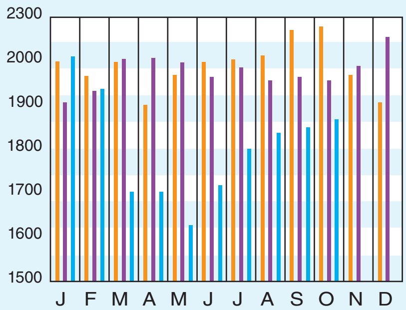
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Nov. '20 = 98.2	Oct. '20 = 98.1	Sept. '20 = 96.1	Nov. '19 = 101.9
CPI value of output, $ billions	Oct. '20 = 1,857.9	Sept. '20 = 1,845.2	Aug. '20 = 1,835.6	Oct. '19 = 2,020.0
CPI operating rate, %	Nov. '20 = 73.5	Oct. '20 = 73.3	Sept. '20 = 71.8	Nov. '19 = 75.8
Producer prices, industrial chemicals (1982 = 100)	Nov. '20 = 228.4	Oct. '20 = 226.5	Sept. '20 = 227.3	Nov. '19 = 250.9
Industrial Production in Manufacturing (2012 =100)*	Nov. '20 = 101.1	Oct. '20 = 100.3	Sept. '20 = 99.2	Nov. '19 = 104.9
Hourly earnings index, chemical & allied products (1992 = 100)	Nov. '20 = 190.6	Oct. '20 = 188.5	Sept. '20 = 191.8	Nov. '19 = 187.1
Productivity index, chemicals & allied products (1992 = 100)	Nov. '20 = 102.6	Oct. '20 = 101.0	Sept. '20 = 100.4	Nov. '19 = 97.4

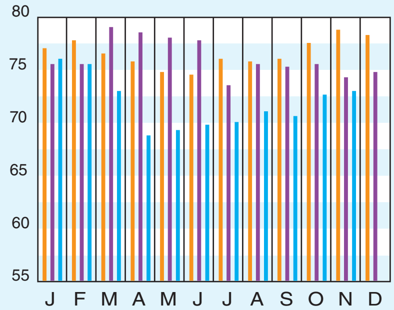
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for October 2020 (the most recent available) increased compared to the previous month's value, after the final September value was revised lower. The October increase continues a period of up-and-down fluctuations in the CEPCI values. The Equipment, Construction Labor and Buildings subindexes increased in October, while the Engineering & Supervision subindex fell slightly. The current CEPCI value now sits at 0.6% lower than the corresponding value from October 2019. Meanwhile, the newest data for the Current Business Indicators (CBI; middle) showed the CPI Output Index edging higher in October and November, and a higher CPI Value of Output for October.